"THE PETROLOGY OF THE CAMBRIAN VOLCANIC ROCKS OF TASMANIA".

by

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PREFACE.

It is suggested that the papers be read in the following order:

(a) The Petrology of the Volcanic Rocks of South East King Island, Tasmania.

(b) A Note on the Occurrence of Intergrowth between Diopsidic Augite and of Hydrogrossular from King Island, Tasmania.

(c) Revised Interpretation of the Geology of the Smithton District of Tasmania, by S. Warren Carey and Beryl Scott.

(d) The Occurrence of Pillow Lavas near Penguin, Tasmania.

(e) Thesis.

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ABSTRACT.

A spilitic suite comprising picrite basalts, spilites, keratophyres, albite dolerites and associated pyroclastics, reputed to be Middle Cambrian in age, forms an interesting petrographic province on the West Coast of Tasmania. The spilites are considered to have been normal basalts which later suffered soda metasomatism as a result of eugeosynclinal orogeny. Like basalts from other orogenic regions these are rich in alumina but the presence of excess alumina in this suite is regarded as being secondary and not magmatic. Fresh diopsidic augite is a feature of some of the lavas. Hydrothermal alteration has given rise to a variety of rock types which includes porphyries, keratophyres, "variolite", spherulitic quartz rock and jasper. Petrological similarity exists in basaltic lavas in Tasmania, South Australia and Western Australia but the Tasmanian lavas which are eugeosynclinal show advanced metasomatic alteration whereas the Western Australian, which were erupted on to the stable shield are unaltered. The South Australian, which are miogeosynclinal, are partially metasomatised.

INTRODUCTION AND ACKNOWLEDGEMENTS.

The purpose of the study was to examine and describe the petrology of the late Pre-Cambrian and Cambrian volcanic rocks of Tasmania and then compare and contrast these with similar rocks of similar age on the mainland of Australia, and in South Africa.

With regard to the study of the Tasmanian volcanic rocks it was decided first to make a detailed study of those which outcrop along the south eastern coast of King Island, since the exposures on the wave cut platforms are extremely well preserved with a minimum of tectonic complication. With this detailed study for comparison other rocks on the west coast of Tasmania were then studied.

Because of the rugged nature and dense vegetation of the Tasmanian West Coast, examination of the rocks in the field and personal collecting were very restricted. Use had to be made of literature on the various areas in the west coast appearing in the bulletins of the Geological Survey of Tasmania and of many slides in old collections. In the Department of Geology, University of Tasmania, the Millen Collection of microscope slides proved very useful and through the kindness of Mr. W.H. Williams, Director of Mines in Tasmania, the author had access to the many slides in the Mines Department. Miss I. Thompson, Director of the Queen Victoria Museum and Art Gallery, Launceston, kindly lent the author several specimens from which thin sections were cut. Although this method of attack was not as satisfactory as personal examination and collection, it did serve a useful purpose in indicating the distribution of the volcanics and the particular rock type occurring in the various localities. Field examination and collections were made on King Island, at Queenstown, Zeehan, Dundas, Leven Gorge, Smithton, Magnet and Penguin.

A full account of the petrology of the volcanic rocks of south east King Island has been published (Scott 1951 (a)) so duplication of information will not be made in this thesis. After reading an account of a so-called dyke at Smithton in Bulletin No. 41 of the Geological Survey of Tasmania the author doubted the conclusions reached by the authors (Nye, Finucane and Blake) of that bulletin so in the company of Professor S.W. Carey visited the area. The results of this visit are embodied in the joint paper of Carey and Scott (1952). A reference by Nye (1931) in the Geological Index of Tasmania to dolerite of Lower Palaeozoic age near Penguin was brought to the notice of the author by Miss E.M. Smith, Geological Indexer for Tasmania, of the Bureau of Mineral Resources. This dolerite was inspected in the field and the short paper (Scott 1952) is the result of the visit.

Thanks are extended to the many people who have contributed specimens and helped in discussion. Mr. Q.J. Henderson of North Broken Hill Pty. Ltd. kindly sent specimens of the lavas in the Torrawangee Series near Broken Hill, N.S.W. and Professor F. Walker of the University of Cape Town, South Africa, contributed several slides of the Ongeluk lavas as well as microfilms of articles from the Annual Reports of the Cape Geological Commission. During a visit to the mainland of Australia in August 1951, the author was very grateful to Professor Sir Douglas Mawson of the University of Adelaide, South Australia, for allowing her to examine rocks and sections of Pre-Cambrian volcanics in the collection of the Geology Department. Thanks are due to Professor E.S. Hills for permission to work in the Department of Geology, University of Melbourne, Victoria, to examine slides of Heathcotian lavas and to Dr. Tattam of the same department for his assistance. Dr. Thomas, Chief Government Geologist of the Mines Department of Victoria was extremely helpful in his discussion with the author on the Heathcotian rocks and in his direction to the best exposures in the field

during a field trip undertaken by the author in the company of Professor S.W. Carey and Dr. M.D. Garretty, the latter kindly supplying the transport. To all these people the author is greatly indebted and wishes to express her thanks.

The academic year, 1949-50, was spent in the Department of Mineralogy and Petrology, University of Cambridge, while the author was the holder of a Rotary Foundation Fellowship. During this year a considerable part of this study was carried out, particularly the section on the King Island rocks which is now published, but above all the author values the various methods and techniques in mineralogy acquired there. To the staff and fellow students of this department she extends her thanks for their help and co-operation.

Special thanks are given to Miss E.M. Smith, Geological Indexer for the Bureau of Mineral Resources, for her help in making the geological index available, and for supplying the answers to many inquiries with regard to localities in Tasmania, and to Mr. M.R. Banks of the Geology Department who was always willing to lend a helping hand and to discuss any problems which presented themselves. Last but by no means least she wishes to express her very great appreciation and indebtedness to Professor S.W. Carey

for his help, encouragement and on several occasions, his company in the field.

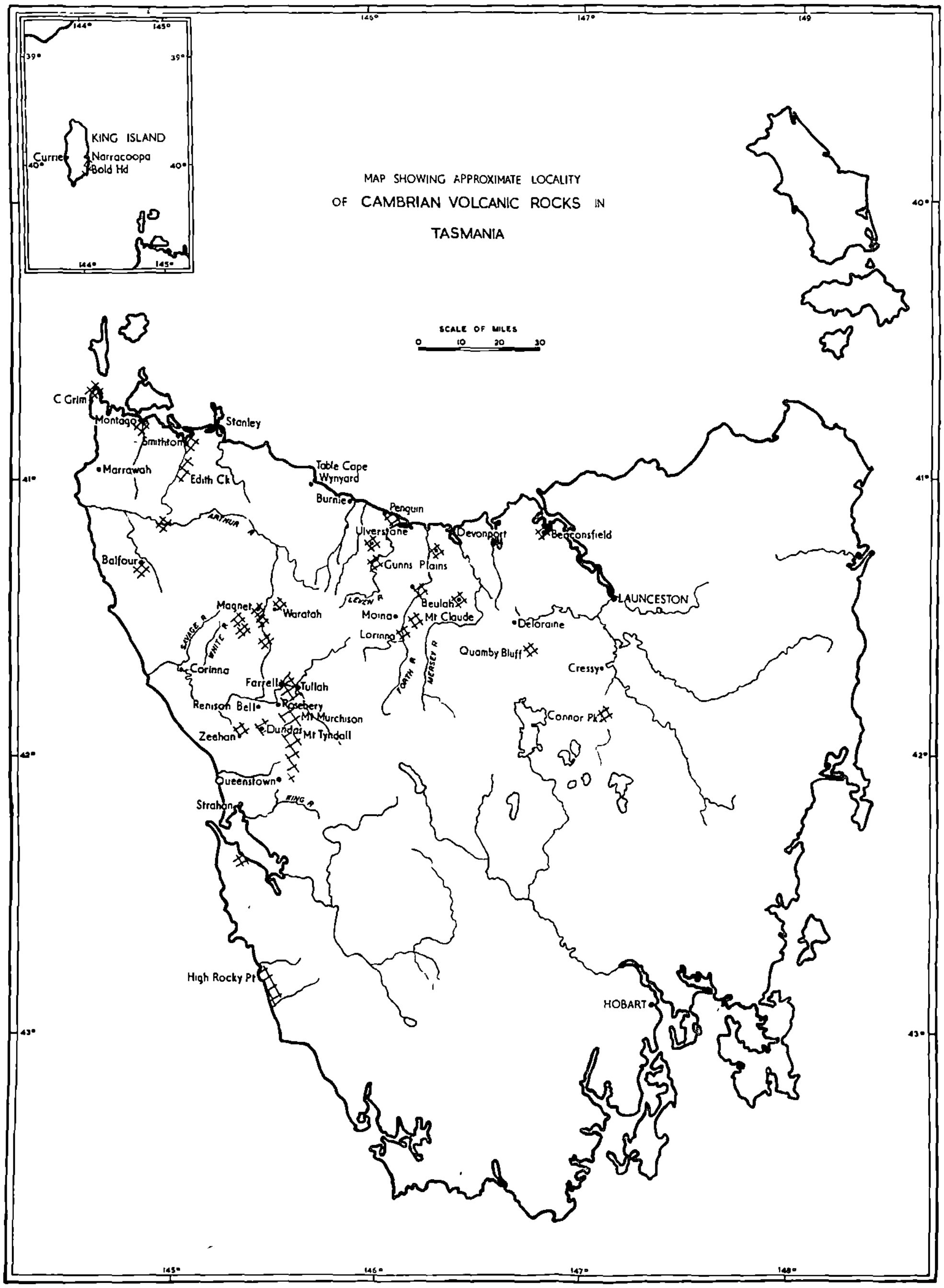

MAP SHOWING APPROXIMATE LOCALITY
OF CAMBRIAN VOLCANIC ROCKS IN
TASMANIA
SCALE OF MILES
0 10 20 30
KING ISLAND
Currie
Narracoopa
Bold Hd
C Grim
Montagu
Smithton
Stanley
Marrawah
Edith Ck
Table Cape
Wynyard
Burnie
Penguin
Ulverstone
Devonport
Beaconsfield
Gunns Plains
Balfour
ARTHUR R
Magnet
Waratah
LEVEN R
Beulah
Moina
Mt Claude
LAUNCESTON
Deloraine
Lorinna
Quamby Bluff
SAVAGE R
WHITE R
FORTH R
MERSEY R
Corinna
Cressy
Farrell
Tullah
Renison Bell
Rosebery
Mt Murchison
Connor Pk
Zeehan
Dundas
Mt Tyndall
Queenstown
Strahan
KING R
High Rocky Pt
HOBART

Figure 1

DISTRIBUTION.

As indicated in figure 1 these ancient volcanic rocks seem to outcrop intermittently along a belt some 30 to 40 miles in width which trends in a northerly direction for about 100 miles from High Rocky Point on the south west coast, through Double Cove on the southern shore of Macquarie Harbour, the Jukes-Darwin District south of Queenstown, Zeehan, Dundas, Rosebery, Mt. Farrell, Tullah and Waratah, thence trending north east to the Dial Range, Penguin on the north coast and in the Leven Gorge. From here it begins to swing south east, the outer boundary being in the vicinity of Beaconsfield and the inner in the vicinity of Quamby Brook. About Cressy the group is concealed by overlying younger rocks. It seems that this broad band of volcanics trends around the stable Central Tasmanian Nucleus or Creto n of Ancient Archaeozoic rocks.

About 30 miles west of Waratah is another band of volcanic rocks, much narrower in width. Its width would be in the order of 2 miles according to present day outcrops. It extends approximately in a northerly direction through Balfour to Smithton on the north west coast of Tasmania. Most probably the volcanics of the south east of King Island which outcrop from Naracoopa in the north to the Grassy River in the south belong to this band. Very little is known about the country in between these bands. Petrologically the rocks in both are similar.

Closely allied with the volcanics are intrusions of basic and ultrabasic rocks which have been serpentinized to a considerable extent. In a later section in this thesis these rocks and their relationship to the volcanics will be dealt with in some detail.

MODE OF OCCURRENCE.

The available evidence indicates that the lavas were emitted in the forms of massive, pahoehoe and aa flows and pillows. Fragmental rocks such as tuffs, breccias and volcanic bombs usually accompanied the lavas.

It is only along the sea coast such as south east King Island, Smithton, Cape Grim and Penguin that this evidence is available because it is there that weathering is ideal for displaying the different structures. Inland no evidence of the type of flow or order of extrusion is available. Detailed descriptions of the above forms are given in the appropriate publications.

The modes of occurrence and the presence of columnar jointing in one of the massive lavas on King Island indicate both subaerial and submarine conditions in that locality. A suggestion has been put forward in the King Island publication to try to reconcile the two. In all other localities submarine conditions are indicated. If subaerial conditions existed they are not revealed in the rocks exposed.

Shallow water conditions probably prevailed during deposition of the sediments in the eugeosyncline but ridges above sea level must have existed. King Island was, no doubt, one of these rising ridges. No volcanic necks or plugs have been found and the nature of the lavas indicates quiet eruption from fissures which was at times interrupted by explosive vulcanicity to account for the tuffs and breccias.

AGE AND THICKNESS.

The age most commonly given these rocks in the older literature is Cambro-Ordovician, although ages ranging from Cambrian to Devonian have been imposed. It is not proposed to give a resumé of the evidence produced by the various workers to support their arguments. Actually, after the work of the earlier geologists, such as Montgomery and Twelvetrees, very little original thought was given to the matter. The later workers were content to quote and requote the evidence of their predecessors. This also applied to descriptions of specimens.

In recent years, particularly since the inauguration of the Geology Department of the University of Tasmania, a great deal of attention has been devoted to the geology of the West Coast. It now seems, from fossil evidence, that the volcanics are of Middle Cambrian age.

At Dundas, trilobites, determined by Opik (1951) to be Middle Cambrian in age have been found in rocks associated with the Curtin Davis lavas reputed to be similar to those at Zeehan. West of Zeehan, trilobites, brachiopods and cystoids have been found in "keratophyre tuffs" which overlie the Montana melaphyres and glacials. These fossils indicate an Upper Middle Cambrian age for these rocks in this area. (Stratigraphy from unpublished work of J.N.W. Elliston).

Although an intensive search has been made, no fossils, to date, have been found associated with the King Island rocks but lithological evidence and their association with glacial tillite seem to indicate that they are of the same age as those in Tasmania. This point was discussed by Carey and Scott (1952).

Elliston's unpublished work on the Dundas District indicates that volcanic material of over 9,000 feet in thickness makes up the Dundas Group (Middle Cambrian) in which the Curtin Davis lavas of approximately 1,000 feet in thickness occur. The author is inclined to believe that most of these tuffs are not true pyroclastics but sedimentary rocks composed of a great deal of transported igneous material and would probably belong to the greywacke suite.

TERMINOLOGY.

The term "porphyroid" was a "sack" into which were dumped by various authors keratophyres, quartz keratophyres, felsites, quartz porphyries, melaphyres and spilites. Even the terms keratophyre, felsite etc. have been incorrectly applied. Apparently the two terms keratophyre and melaphyre were used very loosely as group names and any rock which had the appearance of a keratophyre or melaphyre, or was even associated with them was given the appropriate name.

Actually the term "porphyroid" was first introduced into Tasmania by Twelvetrees and Petterd (1899) when they quoted a description of the Tasmanian rocks sent to them by Professor Rosenbusch. Part of the description reads, .. "The rocks greatly resemble our German occurrences in Westphalia, the Fichelgebirge and Thüringen, and especially the occurrences in Wales. These are the forms which in Germany were originally called porphyroids and flaserporphyries". It was first applied by Waller (1904) in his report on the Mt. Farrell Mining District. The pertinent passage is quoted below.

> "The Mt. Farrell District is situated within a remarkable belt of highly altered igneous and sedimentary rocks, which appear to extend in an unbroken line from the south end of Mt. Darwin northwards along the main axis of the West Coast Range.

The igneous rocks include syenites, syenite porphyries, keratophyres, felsites, quartz porphyries and granites. These rocks appear to belong to one great family, and pass over into one another by gradual transitions .... Another strong characteristic is a certain schistose structure, which in many cases is so highly developed as to completely hide the true character of the rock. I have examined a great number of the so-called schists in the Mt. Read, Rosebery, Red Hills and Middlesex districts, and in almost every instance I found that the igneous character of the rock was masked by the schistose structure. Still some of the schists do certainly appear to be of sedimentary origin and pass over into slates and argillites, and it is often impossible to tell without microscopic examination .... I propose the term "porphyroid" as a provisional group name for the schistose rocks of this series. The name was originally applied to certain schistose porphyries in Europe, which were subsequently shown to be..... "keratophyres" .... some of our schistose porphyries at Mt. Read and Rosebery are true keratophyres; the series, therefore, would seem to bear some resemblance to the old "porphyroids," and until they have been exhaustively studied, I do not think we can do better than adopt the old name.

The origin of these "porphyroids" must remain an open question for the present.... They often appear to run in bands parallel to the schist planes and may be interbedded with the sedimentary rocks. In some cases they are undoubtedly intrusive. Other bands are strongly suggestive of a tuffaceous origin".

Because of the inconsistency in the use of terminology it is very difficult to read the literature. The inconsistency was also evident when examining the microscope slides in the Department of Mines. Similar rocks were given quite different names and the same name was given to dissimilar rocks The author has found it more convenient almost to ignore the terms used by the earlier geologists. Her only use for them is to indicate where such rocks outcrop.

Much confusion exists in the literature dealing with the volcanics of the West Coast of Tasmania. The igneous rocks have been referred to as porphyroids, keratophyres, quartz and felspar porphyries, andesites, melaphyres and syenites. The present author is inclined to believe that the greater part of the volcanics was essentially basic in composition, probably basalts and porphyritic basalts with or without vesicles, and their corresponding pyroclastics. The rock types which are seen today are the metamorphic products of these. The nature and extent of the metamorphism have yielded a great diversity of rock types. It is probably because of an incomplete understanding of the metamorphic processes which were operative that the confusion in terminology has arisen.

PETROGRAPHY.

A full paper has been devoted to the petrology of the King Island volcanics (Scott 1951 (a)) so descriptions will not be repeated here. Likewise, full descriptions of the Smithton lavas appear in the paper by Carey and Scott (1952) and in Bulletin 41. Unlike the King Island suite to which some order of extrusion of types may be given, the author is unable to give any indication of the sequence of the various volcanic rocks from the West Coast of Tasmania.

Because of abundant silicification and chloritization which have affected the rocks it is often difficult to determine their original nature. However, from examination of the least altered specimens it seems that the following types are present.

FLOW ROCKS:

Picrite Basalt.

At Beaconsfield are lavas which perhaps are closely allied to the picrite basalts of King Island. A slide from the Western Tasmania Copper Mine at Beaconsfield shows phenocrysts of olivine now pseudomorphed by calcite and iron ore. The olivine could easily be recognised by its crystal outline and irregular cracks along which occurs iron ore. The olivine pseudomorphs have given rise to a certain amount of glomeroporphyritic texture. The groundmass is fine grained and contains tremolite needles. Veins containing quartz and calcite traverse the rock.

Pyroxene Porphyritic Basalt.

Along Lynch Creek are to be found two fairly thick beds of volcanics. The lower flow is akin to the amygdaloidal Montana melaphyre or basalt while the upper flow with its associated breccia is quite different. Even in the greenish grey coloured hand specimen large idiomorphic phenocrysts of pyroxene can be seen. Under the microscope these phenocrysts exhibit multiple twinning and good cleavage. Sometimes smaller crystals are grouped together to give a glomeroporphyritic effect. The pyroxene is colourless, has an extinction angle of 50° (γ: c), double refraction of 0.030 and an optic axial angle of 52°. Its optical properties indicate a diopsidic augite. This pyroxene has been analysed and the analysis confirms the variety of diopsidic augite as a salite. Phenocrysts of albite up to 1 mm. in size are also present and show a combination of both multiple and simple twinning. Some of the albite shows alteration to sericite and some to chlorite. The groundmass is composed of laths of felspar and granules of augite. Vesicles are rather lacking but when present have been noted to be lined with chlorite and quartz and filled with radiating prehnite or radiating albite with a little quartz.

Slides of rocks similar to these occurring at Beulah, Beaconsfield and Mackintosh River have also been examined. Perhaps the augite porphyrite at Smithton described by Nye, Finucane and Blake (1934) would also fit into this group.

Basalt.

This is the most common type amongst the lavas. It is represented in the Zeehan District by the Montana melaphyre or spilite, at Groom's Slip near Penguin and in the Smithton District by a rock very similar to the massive lava of the King Island suite. Blake (1936) states, "There is a general similarity between the dolerites of this district (i.e. district between the Mainwaring and Wanderer Rivers) and those found near Smithton in the north west of the State, even to the inclusion of small flakes of native copper and patches of epidote". Hence it may be assumed that this is another area in which the rocks are found. According to evidence gained from the study of slides it seems that similar rocks are also to be found at Magnet near Waratah, Heazlewood, Penguin, Leven Gorge, Mt. Claude, Mt. Ramsay, north of Mt. Chester, King River, Dundas and Double Cove. It is most probably to be found elsewhere but generally what are found to-day are its silicified equivalents.

Microscopically the Montana melaphyre is light grey in colour and contains numerous ovate amygdules of dark green to black chlorite. These amygdules range in size from less than 1 mm. to almost 10 mm. in length while the average is about 2 mm. Traces of silicification are evident.

Microscopically the rock consists of numerous lath shaped crystals of felspar up to 0.5 mm. long which have been stained brown. The remainder of the rock is composed of small patches of calcite, chlorite, quartz and fine acicular crystals and tiny grains of iron ore. No primary ferromagnesian mineral is present but it appears that it has been replaced by the calcite and quartz. Under very high power tiny pseudomorphs of chlorite after olivine were observed, the assumption of olivine being based on crystal outline. The felspar is now albite and generally shows no twinning. It is partly altered to calcite, chlorite and quartz and sometimes is surrounded by very small granules of iron ore. Tiny rods of iron ore with crystals arranged perpendicular to them are often seen to grow out perpendicularly from the edge of the felspar. The vesicles are usually filled with chlorite, often with a concentric arrangement, or calcite. In some cases the vesicles are only lined with chlorite and then filled with calcite, while the two minerals may occur together, concentrically arranged. Quartz, too, is known to occur with these minerals in the vesicles. Larger patches of calcite, chlorite and quartz occur in the rock but are distinct from the amygdules. Although not present in great numbers, the patches are probably replacements of some phenocrystic material. Evidence from their shape and other less altered volcanic rocks in the region seems to suggest that the replacements are of a plagioclase felspar. Variations from this general description are the presence of abundant chlorite with a little quartz and/or calcite filling the interspaces of the felspar laths, in other words a variation of these constituents. Granules of sphene and ilmenite are quite common. Sometimes the pyroxene has been replaced by green pleochroic hornblende with chlorite as a subsidiary while in rocks from localities such as King Island, Smithton and Penguin fresh pyroxene still remains. When altered it has been attacked around the edges and along the cleavage and changed to brown unidentified material and green chlorite.

Porphyritic Basalt.

This appears to be a common rock type in the Magnet Range District and resembles the melaphyre to some extent. It has been referred to originally by Twelvetrees (1900) and again by Nye (1923) as a diabase porphyrite.

It consists of laths of plagioclase, probably albite which is now partly sericitized, with tiny granules of epidote, sphene and iron ore. Patches of chlorite sometimes occur. Large tabular phenocrysts of plagioclase up to 3 mm. in length are abundant. The plagioclase is albite and is now partly sericitized, especially towards the centre. It seems as though these phenocrysts were once zoned as the alteration appears to have taken place preferably along certain zones. Veins of chlorite traverse the phenocrysts. Abundant vesicles, ovoid in shape and filled with calcite and radiating sheaves of chlorite, are present. A few small patches of yellow coloured epidote are found towards the centre of the vesicles.

The Curtin Davis lavas which are well exposed near the Montezuma Falls, Dundas, belong to this group. As well as being porphyritic they are vesicular. The phenocrysts of felspar which are idiomorphic to subidiomorphic have been replaced by chlorite, calcite, and quartz while the groundmass which once perhaps consisted of laths of plagioclase and granules of augite now has its minerals replaced by chlorite, quartz and calcite which vary in proportions. Often the constituents are outlined by tiny grains of ilmenite giving a clue to the nature of the original constituent. When the rock has been slightly sheared and more silicified and chloritized it is difficult to distinguish the phenocrysts from the groundmass under crossed nicols.

Glassy Basalt.

Evidence of the existence of glassy lavas is revealed throughout the West Coast. The breccias and tuffs commonly contain fragments of devitrified glass.

In the Leven Gorge there are flow rocks which were once definitely glassy. They contain a few lath and skeletal shaped phenocrysts of felspar up to 8 mm. in length. In some specimens the felspar has been silicified while in others it has been sericitized. The groundmass is extremely fine grained and its constituents are almost irresolvable but seem to be chlorite, felspar and iron ore. In one specimen the devitrification has caused the appearance of spherulitic structure. Fine veins of quartz traverse the rock.

<u>Trachybasalt (felspar basalt)</u>.

Occurring in the Smithton District and Leven Gorge are very felspathic basalts. They consist of laths of albite up to 0.5 mm. in length which are irregularly arranged. The extinction angle of 16° indicates a composition Ab_{96} An_4. The albite shows good multiple twinning and some crystals show interpenetration twins. The edges of the laths have a nibbled appearance. Between the felspar laths is a little quartz and chlorite. A few granules of sphene and ilmenite are present. Sometimes the rock is slightly porphyritic when some of the larger crystals of albite form phenocrysts.

With an increase in chlorite and iron ore this rock passes into the normal basalts. The chlorite and quartz are probably decomposition products of the augite. All gradations between the trachybasalt and true basalt exist. It may be that the Montana melaphyre is more closely related to this group than the more basic basalts.

The name trachybasalt is given for the want of a better name, mainly to distinguish them from the augite rich basalts. Perhaps the name felspar basalt would be better because no evidence as to the composition of the original felspar remains.

Keratophyre.

Although many earlier workers have reported the occurrence of keratophyres and felsites the author does not place much faith in their existence in abundance, being of the opinion (derived after the study of many slides) that the majority are really metamorphosed basic volcanics. (See section entitled "Formation of Keratophyres"). However, along the Comstock Tram at Queenstown she has seen an outcrop of a lava showing the type of fluidal structure commonly observed in such rocks as rhyolites, indicating that the rock may possibly be an original acid lava.

Macroscopically the rock is pale grey in colour and consists of phenocrysts of felspar in a groundmass. Microscopically it is composed of phenocrysts of albite about 1.75 mm. in size. These idiomorphic to subidiomorphic phenocrysts show albite twinning and in parts alteration to calcite and/or sericite. In some cases both simple and multiple twinning are superimposed or twinning is entirely absent. No quartz phenocrysts are present. A few smaller crystals of ilmenite are present and some of these show alteration to leucoxene. The groundmass is mostly felspathic and somewhat granular, an average size of the grains being about 0.1 mm. Twinning is absent but there is considerable sericitization and chloritization with some patches of calcite. A little is present and also a few tiny crystals of apatite.

PYROCLASTIC ROCKS:

Extensive developments of tuffs and breccias from localities throughout the West Coast have been described in the bulletins of the Geological Survey of Tasmania. However, in light of recent detailed work on the rocks of this district which has revealed great quantities of greywackes, it may be that most of the tuffs and breccias described by the earlier workers should be classed as greywackes.

Whenever the lavas were examined in the field, the author found evidence of pyroclastic rocks in the form of tuffs and breccias. Those from King Island, some of which contain fresh glass, have been described in the King Island paper. Likewise, the volcanic breccias and bombs found at Smithton have been described in the appropriate publication (Carey and Scott, 1952).

Breccias occur along Lynch Creek, South Queenstown, and along the Trial Harbour Road at Zeehan. In the former locality the breccia is composed of numerous fragments of volcanic rock, up to 3 inches in size, which have been caught up in the lava. The fragments contain idiomorphic phenocrysts of felspar, now pseudomorphed by sericite, and of a fresh pyroxene set in what has been a glassy groundmass but now shows incipient crystallization. Vesicles, filled with quartz, chlorite and a little sericite, are present. The fragments appear to be the glassy equivalents of the lavas. From its appearance the rock could be classed as a pyroxene andesitic pitchstone but if it has a similar composition to that of the lava, an analysis of which yielded 46.72% silica, it is too basic to be classed as an andesite. It seems that these glassy fragments represent portions of a quickly chilled upper surface of the lava flow which were caught up in the body of the lava after the chilled crust had been fractured by pressure from the flowing lava. Figure 2, plate 1 shows a picture of a glassy fragment in the lava. At Zeehan a somewhat similar feature occurs. Associated with flows of the very amygdaloidal melaphyre is a breccia which is composed of fragments of melaphyre within melaphyre. In spite of their brecciated appearance the term breccia may not be the correct name for these rocks. Actually they are lavas containing numerous cognate xenoliths.

Most of the breccias and tuffs examined by the author could be described in general terms as consisting of fragments of quartz, plagioclase (which, wherever determined proved to be albite), and basic lava, some of which has been glassy, in a fine grained matrix which is generally felspathic and siliceous and contains patches of calcite and chlorite and grains of iron ore, either magnetite or ilmenite. The plagioclase is often sericitized or shows partial alteration to chlorite. In the Mines Department is a slide of a rock from the Persic Mine, Magnet, which has been named a diabase porphyrite. Actually it is a breccia which has been chloritized. It is possible that some of the fragments, judging from their cuspate shape and the nature of their alteration, were glass.

Nye, Finucane and Blake (1934) describe a tuff from Duck Bay, Smithton. Only one outcrop is recorded. Carey and Scott (1952) have not described this tuff in their publication. It is a coarse grained greenish rock composed of angular and subangular fragments of scoriaceous material with some angular pieces of grey or green slate set in a fine grained greyish matrix. The fragments vary in size from $\frac{1}{8}$ inch to 1 inch but average about $\frac{1}{4}$ inch.

Microscopically, the scoriaceous material is seen to consist of rounded pieces of partly devitrified glass. Spherulites and small subidiomorphic crystals of felspar and quartz set in a dense brownish groundmass in which small laths of felspar are the only resolvable minerals.

Nye (1923) describes two varieties of breccia in the Waratah District, a felspathic breccia without mica and a micaceous breccia interbedded with slate. Nye, Finucane and Blake (1934) record the occurrence of similar breccias in the Smithton District but state that instead of these two distinctive types being present there are types representing gradations between the two. Slides of both the felspathic and micaceous breccias were examined. The felspathic breccia is bluish grey in colour when fresh but weathers to a reddish coloured rock. Microscopically it consists of angular fragments of albite and quartz in a fine grained felspathic groundmass. Fragments of altered basalt and fine grained slaty material are also present. Calcite occurs as veins and patches throughout the rock. Haematite grains are secondary. Pale green chlorite is present in irregular patches and as an alteration product of the felspar. Nye (1923) suggests that some of the chlorite may be pseudomorphing augite. The micaceous breccia is a dark grey, fine grained rock which weathers to a brown or brownish-red coloured rock. Microscopically it consists of angular fragments of quartz, albite and mica, both muscovite and biotite, in a fine grained matrix of the same minerals plus haematite and calcite. The calcite occurs as small patches and narrow veins and is an alteration product of the felspar. It also fills small cracks in the quartz. Chlorite is abundant and often replaces biotite. Fragments of basaltic rock also occur. Nye says that these two types of breccia consist of minerals which were originally all of igneous origin but the rocks themselves are of fragmentary origin and the bulk of evidence suggests a sedimentary rather than a pyroclastic mode of formation.

DYKE ROCKS:

Earlier writers such as Twelvetrees (1900), Nye (1923) and (1931) and Nye, Finucane and Blake (1934) regarded large occurrences of the volcanic suite as dolerite dykes.

The work of Nye, Finucane and Blake on the Smithton dyke has been reinterpreted by Carey and Scott (1952) who now regard the dyke as a suite of volcanic rocks which includes pillows of lava, volcanic bombs and breccias. The reasons for the reinterpretation have been published and will not be repeated here.

Likewise in a recent publication by Scott (1952), the dolerite of Lower Palaeozoic age reported by Nye (1931) from Groom's Slip near Penguin has been reinterpreted as portion of the great volcanic suite on the basis of the occurrence of pillows of lava and their association with tillite and finely laminated shales.

Twelvetrees (1900) and later Nye (1923) described the Magnet Dyke which outcrops for about 5 miles in a north easterly-south westerly direction a few miles west of Waratah. The dyke, according to the writers, has an average thickness of about 200 feet and is very complex. It consists of websterite porphyrite which has been dolomitized towards the eastern margin, then diabase porphyrite which contains bands of variolite followed by spherulitic websterite porphyrite. The variolite (and its relationship with the diabase porphyrite) is described in detail by the author in a later section. Inclusions of slates and quartzites belonging to the Bischoff Series have been described by Nye (1923) as occurring in the dyke between the websterite on the east and the diabase porphyrite. Apparently this dyke was a problem to the writers. Firstly, they were puzzled about the relationship of the variolite to the diabase porphyrite and secondly, about the relationship of the diabase porphyrite to the websterite porphyrite. The conclusions reached were that the variolite was probably a magmatic variation of the diabase porphyrite which intruded along a fault plane in the earlier intruded websterite porphyrite.

After reading the literature and examining many slides of the rocks from the Magnet Dyke in the collections of the Mines Department and University, the author began to doubt the validity of the interpretation of the diabase porphyrite as a dyke for the following reasons:-

1. The outcrop of the alleged dyke lies in the general belt of known volcanic rocks of the West Coast.

2. There is general petrographical similarity with known volcanic rocks (e.g. Montana melaphyre, King Island lavas, etc.) based on,

(i) General fine grained basaltic appearance as well as the existence of coarser varieties, as elsewhere.

(ii) Abundance of vesicles which seems too great to be consistent with an interpretation as a dyke rock.

(iii) Hydrothermal alteration similar to the Montana melaphyre even to the formation of spherulitic quartz rock.

3. The presence of volcanic breccia which presumably was found amongst the diabase porphyrite. As mentioned previously, in the Mines Department is a slide of a rock from the Persic Mine, Magnet, which is labelled diabase porphyrite. The rock is actually a breccia.

The author became more convinced her views are correct when she read the following from "Twelvetrees' (1900) report,

> "Subsequent to the middle Silurian, basic and ultrabasic eruptions or intrusions took place, penetrating and displacing the buried sedimentary strata, and forming subterranean masses and dykes of gabbro, peridotite, and pyroxenite. There is no evidence that these deep seated eruptions ever reached the surface, for we see no ancient basalts in this area, unless the diabase porphyrite at the Magnet Mine is regarded as a lava sheet."

and studied the diagram recorded in this report. This diagram is reproduced as figure 2 and indicates the diabase porphyrite as being concordant with the associated sediments.

Recently a field trip was undertaken to try to establish definitely the validity of the author's view that

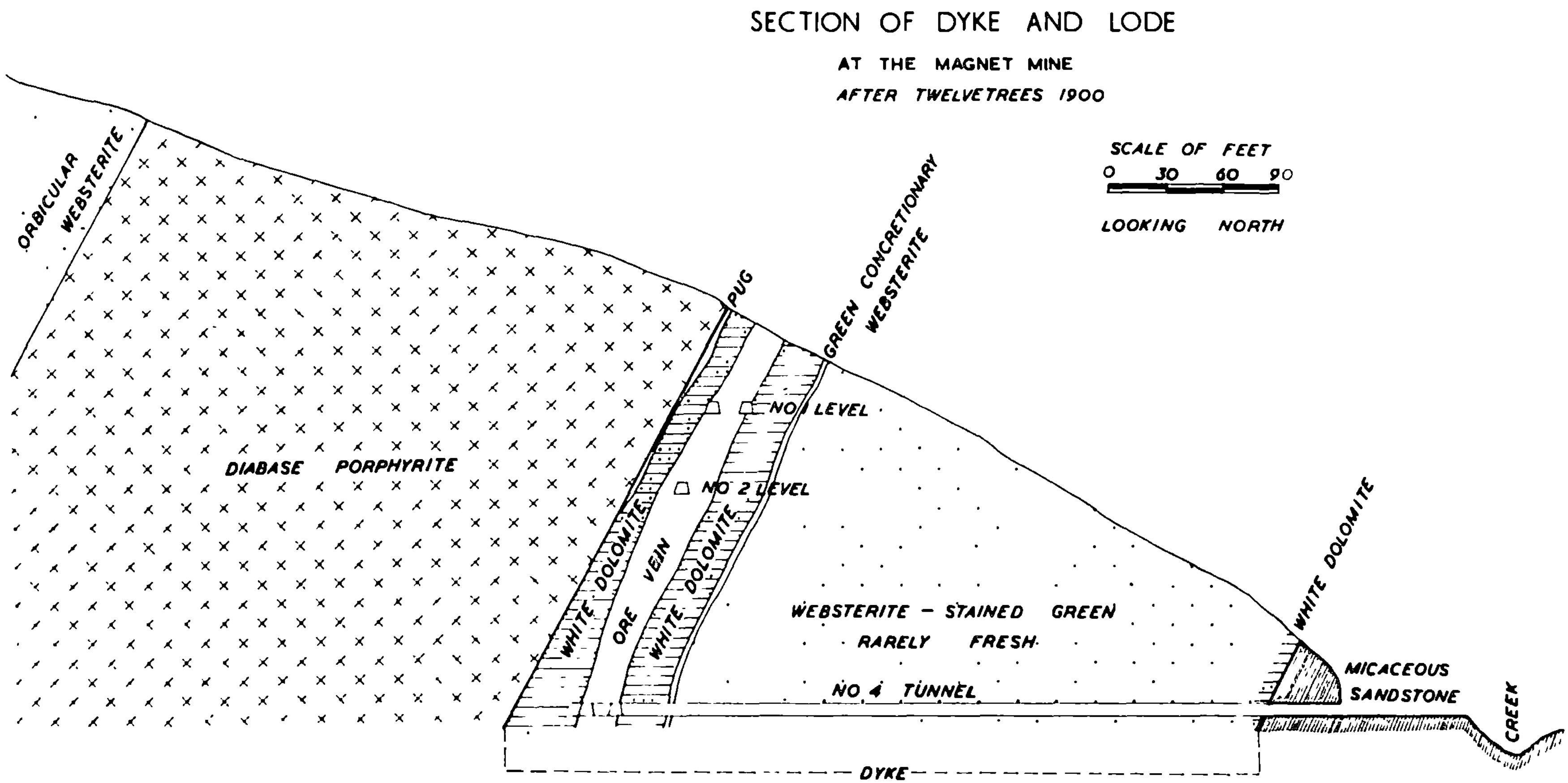

SECTION OF DYKE AND LODE
AT THE MAGNET MINE
AFTER TWELVETREES 1900
SCALE OF FEET
0 30 60 90
LOOKING NORTH
ORBICULAR WEBSTERITE
DIABASE PORPHYRITE
PUG
GREEN CONCRETIONARY WEBSTERITE
LEVEL
NO 2 LEVEL
WHITE DOLOMITE
ORE VEIN
WHITE DOLOMITE
WEBSTERITE – STAINED GREEN
RARELY FRESH
NO 4 TUNNEL
WHITE DOLOMITE
MICACEOUS SANDSTONE
CREEK
DYKE

Figure 2

the dyke should be interpreted as another occurrence of the volcanic suite. However, the trip proved very disappointing because the dense secondary growth of vegetation was almost impenetrable and obscurred the rock outcrops and their relationships. Most of the rock types recorded by the earlier writers were found but it was impossible to establish their relationship with each other.

It must be remembered that the slides examined by the author were cut from rocks brought out from the adits during the days when that portion of the country was being mined extensively for lead and zinc. Most of the information stated by Twelvetrees and later reproduced by Nye was gained from the observation of sections in the adits.

During the trip the author found no evidence to support or deny either the theory of Twelvetrees and Nye or her own, but, basing her view on the evidence gained from the rock specimens and their comparison with others, she still feels sure that if the vegetation were cleared, the adits reopened and the stratigraphy and structure accurately determined, the work would lead to the reinterpretation of the dyke as a portion of the volcanic suite. Throughout this thesis it will be regarded as such.

Associated with the volcanic rocks in most areas where they outcrop is what older writers have termed diabase. To use modern nomenclature, this dolerite is probably the hypabyssal equivalent of the basalts and occurs as cognate dykes and sills.

A general petrographical description of these dolerites would be as follows. The rocks consist of laths of felspar up to 1 mm. in length which have been greatly altered to albite, chlorite and sericite, these alteration products often having a scale-like form. In some cases the pyroxene is still fresh and is often titaniferous as indicated by its slightly pink colour, its only alteration being around the edges and along the cleavages to indeterminate brown material. In the rocks in which the pyroxene has been completely altered, the alteration product is usually chlorite and very occasionally hornblende as in the Leven Gorge dolerites. Numerous patches of mid-green chlorite and abundant iron ore are present. The form of small rectangular to square shaped crystals indicates magnetite while larger plates and grains of ilmenite showing good cleavage and partial alteration to leucoxene are often abundant. Quartz and sphene granules are not uncommon associates of the chlorite.

One of the slides examined in the Mines Department is labelled "Altered Websterite" and bears the locality "No. 13 Stope, Magnet". To the author it seems that this rock resembles one of the ancient dolerites rather than a websterite. The felspar has been sericitized and the pyroxene is now represented by kaolin and carbonaceous material including calcite. Ilmenite, now greatly altered to leucoxene, is abundant.

Nye (1923) describes the occurrence of fine grained pyroxenites along the Waratah-Corinna Road. During the field trip these were examined and even in hand specimens the abundance of felspar would indicate a name other than websterite. A thin section of a sample of this rock yielded the following description. The rock is an altered dolerite. The laths of plagioclase are very sericitized and sometimes show alteration to chlorite. It is almost too altered to allow determination of the variety. On the whole, it has the appearance of albite but a few less altered remnants have extinction angles indicative of the basic variety, labradorite. Remnants of fresh augite with an extinction angle of 40° remain, but most of the augite is altered to brown indeterminate material around the edges, to pale green chlorite and to a grassy green coloured hornblende. Throughout the rock occur patches of secondary quartz and albite which have a shattered appearance and are traversed by tiny veins of calcite and epidote. Patches of epidote are also present. Apart from a few small grains of leucoxene, indicating the original presence of ilmenite, no iron ore is present. The author is inclined to believe that this dolerite belongs to a later suite of basic and ultrabasic intrusions rather than being cognate with the basalts.

HYDROTHERMAL ALTERATION.

The outstanding feature of these old Cambrian volcanic rocks is their hydrothermal alteration which has given rise to a variety of rock types, some of which are quite unusual and are described below.

The chief types of alteration seem to have been albitization, silicification and chloritization.

Albitized Basalt.

This is the simplest rock type developed. As on King Island, at Smithton and Penguin it is quite common to find the pyroxene practically unaltered. The only major form of alteration is the albitization of the plagioclase which may also show partial alteration to sericite and chlorite.

Albitized & Chloritized Basalt.

As the name suggests, in this basalt the plagioclase has been converted to albite and the pyroxene to green chlorite which now occupies the spaces between the albite laths. The albite often shows further alteration to sericite and chlorite while the chlorite is often accompanied by granules of sphene and sometimes quartz with needles of tremolite may be observed in association.

Silicified, Carbonated and Chloritized Basalt.

A very amygdaloidal basalt from Magnet has been completely changed to a quartz, calcite, chlorite rock while the circular vesicles have been filled with chlorite. Not one of the original constituents remains.

The Formation of Secondary Spherules.

Siliceous spherulitic rocks are known from the Montana area at Zeehan. Boulders have also been found in the Castray River, a short tributary of the Pieman and in the Arthur River where it is crossed by the Magnet "dyke", so it seems that the same rock may also crop out some 30 miles north of Zeehan. Twelvetrees and Ward (1910) gave the following description of the occurrence on Montana Flat:

> "Macroscopically, it is somewhat variable in appearance. Some specimens are full-white or greenish-white, and others have a prevalent reddish tinge. There is a white base, which has the appearance of porcellanite, and in this are set the spherules. The spherules are at times so closely packed that no base appears between them. They are pale-green or blood-red in colour, and in many cases both colours are exhibited by one spherule. The radial structure of the spherules is visible to the naked eye, and their average size lies between one-sixth and one-quarter inch in diameter.
>
> In thin sections the spherules are seen to be cloudy, with inclusions, some containing moving bubbles. Their radial nature becomes apparent between crossed nicols. A dark cross then appears, the

> arms of which do not move with the rotation of the slide, but remain parallel with the vibration-planes of the nicols. At times the cross has double arms. The spherules become deformed when closely packed together, yet they preserve their radial structure. Their optical character is positive, as would be the case whether they were composed of quartz or microfelsite. In general appearance the material is quite homogeneous, and resembles quartz.
>
> The centre of each spherule is the meeting-place of the radial structures, which are wavy, and have a scaly imbricated appearance.
>
> The margins of the spherules are bordered with a narrow radial fringe of divergent tufts, substantially, but not exclusively, optically continuous with the substance of the spherules. This fringe shades off into a cryptocrystalline groundmass, like that of the felsophyres, in which are some small spherulites of doubtful nature. The marginal fringes sometimes suggest felspathic or quartzo-felspathic material, but the analysis of the rock shows its composition to be almost wholly silica."

At the time of writing, Twelvetrees and Ward expressed this opinion about the spherulitic rock. "It is so thoroughly silicified that its original nature - if, indeed, it is of a secondary character - is problematical".

The author does not wish to redescribe the rock but to put forward a view as to the possible formation of the spherules. This view arises from the observation of a sequence of stages in the development of the spherules by examining a suite of closely related rocks in the vicinity.

A less silicified specimen found a few feet from the spherulitic rock in the same trench on the Montana Flat is very dark greyish green in colour with light coloured spherules, averaging about 5 mm. in diameter, scattered through it. Microscopically, small laths of felspar are replaced by quartz and chlorite. Quartz is developed between the laths and seems to have taken on a feathery form and a tendency to spherulitic texture as illustrated in figure 1, plate II. Always accompanying the quartz is chlorite, most probably of the pennine variety, which is also developed together with iron ore, sphene and quartz between the embryo spherules. Often iron ore outlines the pseudomorphs after the felspar amongst the chlorite.

After examining this rock it was realised that a similar rock, incorrectly named a chloritized actinolite schist from the Lucy River in the Pieman District and the variolite associated with the diabase porphyrite described by Twelvetrees in 1900 in dealing with the so-called Magnet Dyke, were similar alteration products of the diabase porphyrite.

Examination of thin sections of rocks from Magnet confirmed this view. In the collection from the Mines Department is a slide labelled "quartz chlorite". It is very similar to that described above. The white nodules are composed of beautiful radiating quartz with some granular quartz. Between the nodules are to be found chlorite and calcite predominantly with a few granules of quartz.

On pp. 83-85 of Bulletin 33 of the Geological Survey of Tasmania in a description of the ore body of the Old Jasper Mine a "pseudo-amygdaloidal" variety of hypersthenite is referred to. No doubt the slide from the Mines Department labelled "Amygdaloidal" pyroxenite from No. 3 Adit of the Old Jasper Mine is an example of this. Upon examination it appears to be a stage in the alteration of the old lavas. The white patches have taken on a form as in the spherulitic rock but the material in between is still mainly chlorite with some calcite, quartz and albite. Some of the white nodular patches are of radiating albite which shows slight alteration to kaolin, good cleavage and multiple twinning.

A so-called "altered pyroxenite" from No. 2 Adit of the Mt. Wright Mine is very interesting. The rock on the whole appears to be quite felspathic consisting of laths of albite with pale green chlorite between them. Small vesicles containing radiating chlorite are present. An almost sharp boundary exists between this part of the rock and a part which has been altered to the spherulitic rock with small radiating groups of quartz with some felspar separated by very fine granular quartz.

Below is an extract from Bulletin No. 33 by Nye in which is included a description of a microscope slide of the rock by Professor Rosenbusch which was originally recorded by Twelvetrees in his report of 1900.

> "The diabase porphyrite and the associated variolite occur as a belt 300 to 400 feet wide to the west of the websterite porphyrite. The porphyrite is a very fine-grained, dark-grey rock, in which no minerals are visible to the naked eye. The variolite is a somewhat darker rock in which appear whitish circular nodules up to a quarter-inch diameter. It occurs as narrow, irregular bands up to 3 feet in width in the porphyrite, and also as a margin to the latter. In some places the porphyrite is veined with quartz, generally whitish, but sometimes of a blackish tinge. In the Magnet Mine the junction of the websterite and the diabase porphyrite has a bearing of 20°, and dips westerly at 50°. The following description is the result of a microscopic examination of a specimen (probably from the footwall of the diabase porphyrite) by Prof. Rosenbusch [21] :-
> "If a slide be made of the soft dark-green groundmass (which is soft enough to be scratched with a knife), it can be seen to consist of a scaly aggregate, the scales of which can often be recognised as chlorite, with very weak double refraction, and optically positive; optic axial angle very small. Pleochroism weak, normal - green

for rays vibrating parallel with the surface of the flake, yellowish-white for those vibrating perpendicular thereto. In it are lying colourless sections variously bounded, but always with crystallographic contours, long, rectangular, and prismatic, also nearly quadratic, extinguishing sometimes straight, sometimes oblique. In convergent light these often show the emergence of a positive bisectrix of a not very large axial angle, sometimes the emergence of a negative bisectrix of a very large axial angle. In the first case no structure is recognised; in the second, a more or less scaly or fibrous structure. Their refractive index differs little from that of the main mass, and there are often seen lying in these apparent crystals, green heaps of scales without any clear boundaries, but passing into the colourless substance and having the same optic orientation. In the colourless sections there are also lying homogeneous and homoaxial pseudomorphoses of chlorite, poor in Fe (Leuchtenbergite) after a pyroxene mineral, but I cannot say whether the latter was monoclinic or orthorhombic. Further, in the green mass there are circular hollow spots (nearly always surrounded by cracks), which were no doubt originally amygdaloidal cavities, but are now filled with mixed chlorite and quartz spherulites of irregular architecture. It is quartz (optically + and uniaxial), and not chalcedony (optically - and biaxial). Finally, in the groundmass are little aggregations of iron ore, which I have not examined more closely. They dissolve easily in HCl, which also attacks the chlorite and leuchtenbergite. Now, if a slice be made through the nodules, which are much harder than the ground-mass, and sometimes cannot be scratched with a knife, here and there chloritic spots are seen, containing small sections of chalcedony amygdules. Inside the nodules is sometimes some ground-mass. More frequently, however, the nodules consist of colourless substances. Large aggregates of granular or even radiating, quartz are seen, sometimes without any regular external boundary, sometimes plainly, and without doubt, showing the form of felspar. These are replacement pseudomorphoses of quartz after felspar, of such beauty as I know only in quartz porphyries. Between these pseudomorphoses of quartz after felspar there are roughly-radiate bundles and spherulitic crystals of felspar, which from their optical behaviour clearly belong to orthoclase or andesine. They are partly converted into sericite, and when this happens the nodules can be scratched with a knife. Finally, the nodules are much intersected by veins of quartz, the fillings of cracks in the rock. Iron ores are absent; but, from the often quadratic and trigonal outlines of the quartz aggregates, I believe we must conclude that the ores have been removed and their place taken by quartz. After all said and done, I regard the rock as characteristic variolite, but certainly in a much altered state."

An examination of a number of specimens under the microscope proves the rock to vary in composition from place to place. The specimens were all much decomposed, and rendered identification difficult, the above description of the ground-mass applying generally to the specimens. The fresher specimens, however, prove the original rock to have been composed of felspar and pyroxene. The felspar is generally alltriomorphic and granular, but in one section it appears in the form of small laths. Lamellar twinning is common in some sections, but generally the felspar is untwinned. The pyroxene mineral cannot be determined as it is always completely altered, but it was probably a monoclinic pyroxene. Chlorite and calcite occur abundantly as alteration products. Sometimes felspar is largely in excess, and with calcite forms the bulk of the rock. When the section is composed of nearly all chlorite it would appear that the pyroxene mineral was in excess."

At Zeehan and Magnet this so-called variolite and spherulitic rock are intimately related with the Montana melaphyre and diabase porphyrite respectively, i.e. with old basalts, both vesicular and porphyritic. The following is an outline of the suggested formation of the spherules.

1. The spherulitic rock is probably derived from a more basic lava such as the Montana melaphyre in which the first stage is the development of quartz, chlorite and sometimes calcite between the felspar laths, i.e., a break down of the pyroxene.

2. The quartz takes on a feathery form with spherulitic tendency (figure 1, plate II) while the chlorite is pushed out to between the embryo spherules.

3. With the addition of more silica complete spherules are developed with fringes of radiating quartz and with fine granular quartzitic material between. This is illustrated in figure 2, plate II.

4. The radiating fringes grow outwards from the spherules at the expense of the fine granular material which they incorporate. These fringes continue to grow until all the granular material has been consumed and a perfect spherule is developed in the area formerly occupied by the minute grains of quartz. Figure 3, plate II illu-

strates this phenomenon.

5. In some cases the fine grained material increases in grain size and finally unites and at the same time the radiating fringes grow out. It has been noted, as indicated by figure 2, plate III that at the junction of the two a crack develops.

6. Figure 3, plate III, illustrates the final development of the spherulitic rock which is the stage when all the spherules are close together with no granular material between them.

It seems that the formation of the secondary spherules represents an interesting case of silica metasomatism. Below are analyses (Table I) of the rocks in the various stages of alteration. Assuming that the original lava was somewhat similar in composition to the least altered lavas of King Island and Smithton it is interesting to note the changes as the rock approaches its spherulitic goal. This is illustrated by the variation diagram (figure 3). With an increase in silica there is a decrease in all other constituents.

The Formation of Porphyries:

Scattered throughout the West Coast are the controversial quartz, quartz felspar, syenite and granite

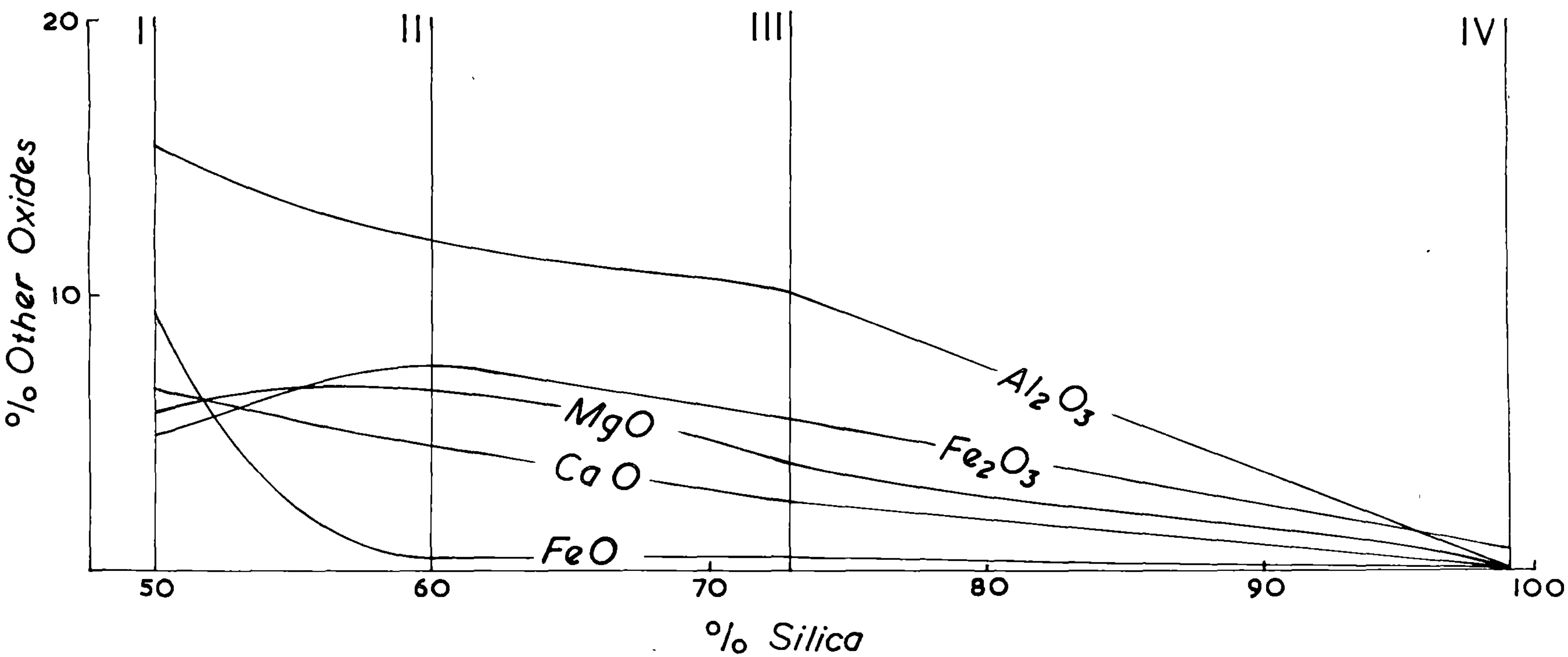
TABLE I

	I	II	III	IV
SiO_2	50.01	60.00	73.00	99.11
Al_2O_3	15.38	11.97	9.95	nil
Fe_2O_3	4.86	7.68	5.29	0.75
FeO	9.21	0.39	0.39	Tr.
MgO	5.85	6.50	3.84	nil
CaO	6.53	4.35	2.30	nil
CO_2	0.13	8.90	5.90	nil
FeS_2	-	0.24	0.57	nil
		100.03	101.24	99.86

I Spilite (basaltic type), King Island, Tasmania. Anal. B. Scott.

II & III Variolite from Magnet Mine, Tasmania, (different portions of same specimen). Anal. Geol. Surv. Lab. (Bulletin No. 33).

IV Spherulitic quartz rock, Montana Flat, Tasmania. Anal. B. Scott.



20
10
% Other Oxides
I
II
III
IV
Al2O3
Fe2O3
MgO
CaO
FeO
50
60
70
80
90
100
% Silica

Figure 3

porphyries. Their mode of origin has been discussed by writers as being on the one hand intrusive and on the other replacement, i.e. derived from metasomatically altered sediments and volcanic rocks. The author does not wish to deal with the formation of the porphyries in detail as this is being done by a colleague, Mr. J. Bradley, formerly of the Geology Department of the University of Tasmania, now of Victoria College, University of New Zealand. She is interested in them so far as they are related to the volcanics.

There is undoubted evidence that some of the volcanic rocks, both lavas and associated pyroclastics, have given rise to the development of "porphyritic" (i.e. porphyroblastic) rocks. This, however, does not mean that all the porphyries were originally volcanic. In fact there is evidence of sediments being "porphyritized" too.

The region of greatest development of these rocks is at Queenstown (Mt. Lyell) and Read-Rosebery District or, in other words, along the crest of the West Coast Range geanticlinal structure.

The alteration begins by a complete replacement of the original rock by quartz and albite to a very finely granular quartz albite mosaic rock. With further silicification some of the quartz grains seem to coalesce and eventually take on the appearance of a quartz "phenocryst" even to the extent of the development of well defined crystal faces (See figure 2, Plate VI.) It is noticed that it is not uncommon to find such idioblasts surrounded by very fine (finer than the groundmass material) granules of quartz as though the quartz had to be as fine as possible before it could be absorbed or "digested". This phenomenon is illustrated in figure 1, plate VI . Misch (1949) describes similar "replacement borders" when discussing the metasomatic origin of granite-porphyry from the Sheku area in China. Likewise, as soda metasomatism advances albite "phenocrysts" are developed from the minute granules of the groundmass.

Not only idioblastic quartz and albite but also hornblende seems to grow into euhedral porphyroblasts by a similar process. Specimens of rocks collected by Mr. M.R. Banks along the Tyndall Track near Lake Margaret were examined. According to Mr. Banks, the rock in the field shows evidence of flow structure in the alignment of hornblende "phenocrysts" and contains many cognate inclusions. (See figures 1 - 3, plate IV.)

In the hand specimen the rock consists of beautiful idioblastic crystals of fresh hornblende up to ½ inch in length, and smaller crystals of felspar in a grey coloured stony groundmass. On the first appearance it could be classed as hornblende andesite. In thin section the rock consists of these large idioblasts of green hornblende which show good cleavage, strong pleochroism, and both simple and multiple twinning, abundant "phenocrysts" of plagioclase and a few of quartz and orthoclase in a fine grained groundmass. Observation of a number of slides indicates that the groundmass varies. Sometimes it is composed of tiny laths of felspar with chlorite, calcite and granules of sphene, in others it is predominantly felspathic with some quartz while in still others it is predominantly quartzitic with some felspar. With an increase in quartz in the groundmass there is an increase in quartz "phenocrysts". These quartz "phenocrysts" seem to be secondary and always show the "replacement borders". (See figure 1, plate VI). The plagioclase shows slight alteration to sericite. It has an extinction angle of 16° and as its refractive index is less than that of Canada balsam the variety is albite with the composition Ab_{96} An_4. Just how much of the plagioclase originally belonged to the lava and how much is secondary is difficult to say. The porphyritic lavas which are fairly common on the West Coast contain phenocrysts of both augite and plagioclase but there is definite evidence that some of the "phenocrysts" of albite are secondary. They, too, show the "replacement border".

There is evidence to suggest that this rock did not originally crystallize as a hornblende andesite but as a pyroxene porphyritic basic lava (Cf. Lynch Creek type) which has since been greatly altered. This clue is given by the presence of augite which is in the various stages of being altered. The first change appears to be in the formation of chlorite around the edge and along the cleavage planes and cracks of the augite. As alteration proceeds tiny granules of sphene and epidote are developed and even a little iron ore. The end stage is a complete pseudomorph after the idiomorphic augite by chlorite and sphene. At a later stage hornblende is born out of these alteration products. The power of crystallization is apparently great because soon afterwards idioblastic crystals are developed. Sometimes patches of the unincorporated alteration products are left as inclusions or "embayments" in the hornblende and inclusions of idiomorphic albite crystals are quite numerous. It seems that the hornblende began life as tiny needles which gradually coalesced to give a plate of the mineral. Upon close observation, fringes of the hornblende which have a similar optical orientation to the plate traverse the mass of alteration products. In the same specimen all stages from the break-down of the augite to the formation of the idioblasts of hornblende may be traced. This feature is illustrated in figures 1, 2 and 3 of plate V. Evidence is also revealed that hornblende is, in some cases, a direct alteration product of the augite. In ordinary transmitted light it is often difficult to distinguish it from chlorite with which it is closely associated. In fact, one mineral seems to merge imperceptibly into the other.

The mode of origin of this rock is very controversial. According to Hatch, Wells and Wells, (1949) the hornblende of hornblende andesites is usually the brown "basaltic" variety and generally shows that it is not in equilibrium with the magma because all degrees of magmatic resorption are displayed. They say "At an early stage this may amount to no more than a slight "peppering" with magnetite granules, but at a later stage of alteration the hornblende is progressively replaced by an aggregate chiefly consisting of granules of nearly colourless clinopyroxene and octohedra of magnetite".

After critically examining the thin sections of this rock the author is of the opinion that the reverse is true. The clinopyroxene, a stable diopsidic augite, is in keeping with the variety suggested as being typical of andesites.

The alignment of the hornblende "phenocrysts" is suggestive of a primary origin but the petrographical evidence is against such an origin. The pyroxene which is usually stable shows more alteration than the usually less stable hornblende. The needles of hornblende, optically orientated similarly to the rest of the hornblende, cut across what Hatch, Wells and Wells would regard as the alteration products of the hornblende. One may suggest that if the hornblende is secondary after pyroxene then the pyroxene originally was orientated in the direction of flow. The hornblende, as suggested is usually not directly formed from the pyroxene but is the metamorphic product of its alteration products (chlorite, epidote etc.) However, some slides show hornblende directly replacing pyroxene. If the pyroxene was originally orientated then the hornblende must have grown with the same orientation, yet in most cases none of the original mineral was left to control the direction of growth of the new mineral. Another suggestion is that the orientation of the hornblende crystals may be a metamorphic effect but the rocks in general do not exhibit structures indicative of dynamic metamorphism. According to Mr. Banks the direction of alignment is at an angle to the cleavage. If, as the author thinks, this rock is not a true hornblende andesite the orientation of the hornblende remains a puzzle.

In the Mines Department is a slide, cut from a rock from the Quo River, labelled "Felspar Quartz Porphyry". It is an interesting rock, because in the groundmass are remnants of the fine grained basaltic lava. In fact, it appears as if the lava is changing to a porphyry. Phenocrysts of both augite, some showing slight alteration to chlorite and epidote, and albite are present in a groundmass containing quartz, felspar, chlorite and granules of sphene. A similar rock occurs at Farrell Siding but the slide of this was unnamed. It contains patches of calcite, the shape of some indicating that they may be pseudomorphing pyroxene. Some of the patches of granular quartz with a little calcite give the same effect. This rock is amygdaloidal, the amygdules, being oval in shape and about 2 mm. in size, are of quartz and calcite.

Another rock slide labelled "Syenite porphyry" from the Tasmanian Copper Company's Water Race at Rosebery is actually one of the felspathic basalts. It consists of irregularly arranged laths of albite with phenocrysts of albite. Between the albite laths is chlorite while patches of calcite and quartz are common and iron ore and flakes of sericite are scattered throughout the rock.

The author does not wish to be dogmatic and state that all the porphyries and porphyrites of the West Coast of Tasmania are of secondary nature. She does suggest, however, that those so-called "porphyroids" and augite porphyrites which contain phenocrysts of augite of the salite variety and albite with or without quartz in a felspathic groundmass are to be suspected of having a secondary origin. Earlier workers have regarded rocks bearing albite and augite (both considered primary) as occurring in minor intrusions and representing the acid differentiate of the basic and ultrabasic rocks. However, the present writer considers the albite of all such rocks as secondary.

The Formation of Keratophyres.

The terms porphyry, porphyroid, keratophyre and felsite have been indiscriminately applied in the past. Similar rocks have been given any of the above names. After examining many specimens and microscope slides of these rocks the author is at a loss to determine the criteria on which some specimens were called porphyries, some keratophyres and some felsites because to her there is practically no difference. If the term porphyroid is used as it was originally meant then some of these rocks could correctly be referred to as porphyroids because many are sheared and even some of the phenocrysts have a "rolled out" appearance.

Twelvetrees and Petterd (1899) describe some of the felsites and associated rocks of the Mt. Read District. They considered the rocks to be lavas which were contemporaneous with the argillaceous sediments which are now converted to schists. These authors sent specimens to Professor Rosenbusch for confirmation of naming. The following description was returned "Undoubtedly we have here strongly dynamically altered forms of the acid eruptive rocks. The typical porphyritic structure, the nature of the phenocrysts, the still recognisable fluidal structure, the nearly entire absence of dark constituents, the occasional spherulitic forms still recognisable in their replacement products (quartz, albite) all point with certainty to members of the quartz porphyry family, and with great probability, not to quartz porphyry in the narrower sense, but to quartz keratophyre and keratophyre".

Ever since then similar rocks and even dissimilar associated rocks have been classed as one of the rock types mentioned above, without any other reason.

In summarizing their descriptions they say, "The rocks have a compact quartz - felspathic (felsitic) groundmass, with quartz and orthoclase and albite phenocrysts, sometimes distributed sparingly, at other times so crowded as almost to lose the porphyritic stamp. In the typically porphyritic varieties are altered spherulites and signs of flow structure".

In all the slides examined by the author she failed to note spherulites (excluding the spherulitic quartz rock) or true flow structure. Actually the flow structure is a pseudo flow effect and is very misleading. It is really a schistose structure as indicated by the direction of the sericite streaks. Often these streaks curve between the "phenocrysts" which being brittle commonly exhibit fracture although some of the felspars have been "rolled-out". In the field the weathering of the schistose structure resembles flow structure but when sections of the rock are examined the schistose nature is readily recognised. In the petrographical section under the heading "Keratophyres" flow structure observed in the field was mentioned but even this may prove to be incorrect.

It is interesting to note that Twelvetrees and Petterd note that "The felspars in the Ring River adit have been replaced by aggregates of secondary albite and quartz" and "The porphyritic felspars are here, too, surrounded by secondary felspathic growth". An entirely opposite interpretation has been put forward to explain such phenomena in the previous section.

Diopsidic augite has been observed in some of the so-called keratophyres. Mawson and Dallwitz (1944) describe similar rocks from south eastern Australia in which pyroxene is present. In fact they have correlated these rocks with the Tasmanian porphyroids. (See section entitled "South Australia"). To the author the presence of such a pyroxene, and especially one of identical composition which is prevalent in the associated basaltic rocks indicates an anomaly. If these keratophyres are soda rich rhyolites why should they contain a pyroxene? The author can recall no normal rhyolite which contains pyroxene.

The formation of these keratophyres seems to be similar to that of the porphyries outlined in the previous section.

Some original acid volcanic rocks may have existed. If they did it is now impossible to distinguish them from the very metasomatised basaltic rocks. However, it is interesting to note that on King Island, at Smithton and Groom's Slip near Penguin where the freshest basaltic rocks occur no acid eruptives comparable with a keratophyre have been found, the most acid differentiate being the trachybasalt (felspathic basalt). Also, the keratophyres seem to be restricted in occurrences predominantly to the zone of the structural weakness where metasomatism has been at its maximum. Surely, if true acid volcanic differentiates existed, a trace of them would have been found with the freshest basaltic rocks.

The above views on the formation of the spherulitic quartz rock, porphyries and keratophyres may seem to be those of an "extreme transformist" but actually they are those of a conservative petrologist who has had to be guided by what she has seen with her own eyes.

The Formation of Jasper.

Jasper "bands" are commonly associated with the lavas in most localities where they outcrop and have been recorded in the literature.

At Groom's Slip, just east of Penguin where the lavas outcrop strongly along the coast they are associated with regularly shaped blocks and bands and irregularly shaped patches of red jasper. Some of the bands are up to about 8 feet in length and about 1 to 2 feet wide. The jasper is the usual red colour and is very finely crystalline. Sometimes it carries a considerable amount of pyrite and in places is associated with green epidote. In a report on the argentiferous lead ores at Penguin, Thureau (1881) states "... huge blocks of hornstone and jasper crop out, containing large numbers of pyrites stained green, thus indicating the presence of copper along that channel of country." Twelvetrees (1903) reports in the following words the occurrence of jasper from a shaft put down by the Wealth of Tasmania Copper Proprietary in the Heazlewood District: "... a seam of red jaspery rock which broke off into boulders in working" and "Between this mine and the Heazlewood Mine some jasperoid hornstone-looking rock has been worked in boulders".

As well as bands of jasper abundant veins of quartz cut irregularly across the lavas in all localities.

The occurrence of jasper with basic lavas is not restricted to Tasmania. Skeats (1908) records the association of jasperoid material with the Heathcotian rocks in Victoria. He writes "Under the microscope the original structure and minerals of the diabase have been completely lost. The rock now consists of a chalcedonic replacement, stained red by haematite, probably derived from iron containing minerals in the original diabase. The deposition of the iron oxides has been irregular, darker and opaque areas passing across the section in bands. The chalcedony has crystallized from centres in radiating groups of crystals. Their boundaries are defined in the rock section by colourless lines of secondary silica. In polarised light these radiating aggregates show irregular black crosses," and

"In the Heathcote District it is safe to regard the jasperoid wherever found, as being one of the forms of silicified diabase". Similarly bands of jasper associated with the Ongeluk volcanics in South Africa are reported as follows in the Annual Report of the Cape Geological Commission for 1906. "The stratified sedimentary rocks other than volcanic debris associated with the lavas consist of banded jaspers." In fact, the association of jasperoid rocks is reported from many localities in the world from which spilitic rocks are recorded.

The question now arises as to the origin of these jasper rocks. Skeats (1908) in his description quoted above regards them as one of the forms of silicified diabase. Based on the evidence of the formation of the spherulitic quartz rock which is perhaps a modification of the jasper the author is in agreement with Skeats and regards them as being the silicified equivalents of the old lavas especially as they are associated with each other so intimately. However, Turner and Verhoogen (1951) on p. 203 write "...from the widespread occurrence of jasper and manganiferous sediments in close association with spilites, it would seem that silica, iron, manganese, and perhaps magnesium are the main constituents of late magmatic solutions emanating from spilitic rocks. A number of writers believe that silica in particular is commonly expelled in such vast amounts as to allow its precipitation, either by chemical or by organic agencies, to give those thick extensive beds of chert with which spilitic lavas so frequently are associated." From this extract it seems that Turner and Verhoogen consider the silica to have been derived from the spilitic rocks but the author believes that the lavas, themselves, under discussion in this thesis have gained silica from an extraneous source. The origin of the silica will be discussed later.

__Nature and Origin of the Chemically Active Solutions.__

When writing the paper on the suite of volcanic rocks outcropping on King Island the author dealt with the facts of the hydrothermal solutions as they presented themselves and drew conclusions from these. However, at the time of writing, the study had been confined to a small area but since then work has been done on a broader area and it now seems that the conclusions drawn from the King Island study will not hold for the Cambrian volcanic rocks in general in Tasmania.

As mentioned earlier, the predominant types of alteration are albitization, silicification and chloritization. The first two are particularly important because they imply the addition of material, soda in the case of albitization and silica in the case of silicification. Generally, the formation of chlorite requires no additional material but as indicated in a later section alumina has been added to the lavas.

Many theories have been put forward to try to explain the origin of albite in spilitic rocks. The theories may be grouped under one of the three headings, primary, deuteric or secondary. For the albite to be of either primary or deuteric origin one must postulate a soda rich magma as in either case the soda, whether it crystallized early in the form of a sodic plagioclase, or later when in the form of a soda rich solution, it affected the earlier crystallized more basic plagioclase and converted it to albite, belongs to the magma. However, on the West Coast of Tasmania not only the lavas and their associated pyroclastics have been albitized but the sediments have also been affected so one must look further afield than the lavas for the source of soda. This fact is also borne out when the relative time of alteration is considered. Albite is the only plagioclase present in the lavas which are associated with a suite of greywackes also containing albite. In view of the formation of greywackes, i.e., rapid erosion and deposition in a geosyncline, the albitization must have taken place either before the formation of the greywackes in which case the albite was derived as such from the lavas or after their deposition. Chlorite and other secondary minerals associated with the albite are abundant in the greywackes as in the lavas indicating that albitization followed deposition. It seems then that a secondary origin for the albite is assured.

An origin of a secondary nature could be brought about in the following ways:

(i) weathering.

(ii) shearing, or

(iii) extraneous hydrothermal solutions.

The first two possibilities may be passed over quickly. The albitization is far too widespread and the rocks too fresh to entertain the idea of weathering. If shearing was responsible then the albitization would be very local. The general structure and the nature of the rocks do not exhibit evidence of sufficient widespread shearing. It seems that one must look to a hydrothermal origin for the albite.

Professor Carey suggested to the author that the soda rich lavas on the West Coast of Tasmania (in fact spilites in general, the world over) were not derived from a soda rich magma but were normal basalts which were later albitized, the albitization being due to burial in a geosyncline. Other factors in the alteration suggested were the thickness of geosynclinal sediments underneath the original basalts, the temperature reached by the base of the sedimentary prism and the permeability distribution in the geosyncline, the temperature being considered the most important of all.

Turner and Verhoogen (1951) suggest that the marine environment of spilites may be directly responsible for the source of Na^{+} ions. They are mainly concerned in deriving an origin for the Na_2O in the magma and not also in the surrounding sediments. They suggest that it is not improbable that sea water entrapped, vaporized and streaming upward through hot but largely solidified submarine basic lavas, could bring about the type of alteration commonly observed in spilites and could also contribute Ca, Fe, Mn, Mg and Si to the surrounding sea in sufficient quantity to account for the chemically precipitated cherts, jaspers and manganese ores, and possibly limestones associated with many spilites.

Misch (1949) regards the source of soda and silica to be below the geosynclinal prism, even below the lower boundary of the sial zone, because he considers the amount of soda and silica added during metasomatism to be in excess of that normally found in rocks of the geosynclinal prism. Misch states "Though part of the sediments in geosynclines have sufficient or excess silica, the granitization of many geosynclinal sediments and nearly all geosynclinal volcanic rocks requires additional silica, often in considerable amounts. A large amount of silica will usually be provided by transfer from silica-excess sediments, but it appears very likely that additional silica is introduced from beneath the geosynclinal prism. This is suggested by the fact that the granitizing agent has in most cases been able to satisfy the needs of silica-deficient rocks, irrespective of the composition of the geosynclinal column in individual areas. Also in some regions quartzite members have escaped granitization and thus kept their excess silica. The considerable amounts of alkali consumed in regional granitization could not be supplied by mere redistribution of the alkali originally contained in the geosynclinal rocks, for as a whole the geosynclinal column is alkali-deficient in comparison to granite rocks and there is no evidence of a regional loss of alkali in the non-granitized portions of geosynclinal bodies. Moreover, among sediments alkali is chiefly contained in argillaceous rocks in which K_2O is greater than Na_2O."

Even Reynolds (1947) states that the result of chemical interchanges between adjacent rocks during granitization may start with the introduction of small amounts of sodium and silica into pelitic rocks in geo-synclines.

In a discussion with Professor Carey on Misch's suggestion he expressed the opinion that it was unnecessary to go beyond the geosynclinal rocks for an adequate supply of soda and silica. A redistribution of the normal content of these constituents in the sediments is sufficient. In the pre eugeosynclinal phase of most geosynclines there are appreciable thicknesses of ortho-quartzites and other highly siliceous rocks which yield their surplus silica to subsequent vagrant fluids. The soda content of the initial connate water seems sufficient to account for the albitization. The author wishes to keep an open mind on this point until sufficient detail is available to enable calculations to be made of the proportions of soda and silica in normal geosynclinal sediments and metasomatised geosynclinal sediments. In the case of a deficiency of soda the Na^{+} ions for its formation could easily be derived from the sea water which is present in the pores of the sediments. They would be driven out and forced upwards during compaction and folding. The alumina could have been derived as an excess constituent from some of the pelitic sediments.

The author is convinced that the soda metasomatism which has affected the basaltic rocks is due to a geosynclinal environment. Although depth of burial is an important factor it does not entirely control the proportion of alteration. In the miogeosyncline of South Australia where the basalts are associated with 40,000 - 50,000 feet of sediments they have only spilitic tendencies, yet in the eugeosyncline of Tasmania where the lavas are associated with 20,000 - 30,000 feet of sediments they have been completely albitized. It is the eugeosyncline which usually suffers orogeny so it seems that heat and perhaps crustal movement are necessary to activate the hydrothermal solutions. The author, therefore, agrees with Professor Carey that heat is perhaps the most important factor of all.

The relationship of the metasomatism to orogeny is dealt with in a later section of this thesis.

The solution could not possibly have been above its critical temperature and pressure because of the assemblage of minerals produced. The assemblage of minerals - albite, chlorite, calcite, quartz etc. - developed as a result of metasomatism is not indicative of high temperature formation. It could be formed readily at temperatures below 300°c.

The formation of hydrogrossular, which is rather restricted requires a higher temperature (See Scott 1951 (a)) but on King Island where it is developed the intrusion of granite during the Tabberabberan orogeny of Middle Devonian age could perhaps account for the higher local conditions of temperature. The formation of hornblende in the porphyries and the lavas also possibly requires a slightly higher temperature. Petrographical evidence indicates that hornblende developed after the low temperature alteration so it may have been formed during the rising crescendo of the Tyennan (Late Cambrian) orogeny or since it is developed most strongly in rocks along the structural weakness any rise in the temperature below (possibly during the Tabberabberan orogeny) could be transmitted readily to the rocks above. However, this point is discussed in a later section.

The author prefers the suggestion that metasomatism has taken place by diffusion of dissolved material through pore fluids (or gases) and the movements of these through intergranular spaces rather than by "solid diffusion" through crystal lattices.

MINERALOGY.

There is not a great deal of variety in the mineralogy of the rocks under study. It seems that the original rocks consisted mostly of plagioclase and pyroxene with iron ore. Some contained olivine but these were in the minority. Any variation has been brought about by the hydrothermal alteration. Even so, the minerals produced are very few in number and are dealt with below.

Plagioclase.

The only member of the plagioclase family observed in the Cambrian volcanic rocks is albite which invariably is almost pure having the composition $Ab_{98}An_2$ as indicated by a maximum extinction angle of $18\frac{1}{2}^{\circ}$ in sections belonging to the zone normal to the 010 face. No trace whatsoever of a more basic member has been found.

Its form is generally as small lath-shaped crystals with no definite arrangement. Some phenocrystic albite has been described and in one of the lavas from King Island (Scott 1951 a & b) albite is intergrown with diopsidic augite and sometimes bears an ophitic relationship to the augite. Albite is commonly found in vesicles and veins.

Usually the albite is water-clear and may or may not have lamellar twinning. Its alteration products are sericite and chlorite although from King Island the author records the alteration to hydrogrossular.

The question arises as to whether the albite is primary or secondary. This was discussed by Scott (1951 a & b) but will be dealt with in some detail at a later stage in this thesis.

Pyroxene.

Whenever pyroxene occurs in the rocks it is usually very fresh. In the King Island rocks it is found associated with albite, in some cases ophitically related, in others intergrown, or merely as interstitial grains. In the Lynch Creek lavas it is well developed as idiomorphic phenocrysts and in some of the quartz and quartz felspar porphyries and porphyroids the pyroxene remains as unaltered idiomorphic to subidiomorphic phenocrysts.

As indicated in the King Island report and in an earlier section the optical properties indicate a diopsidic variety of augite.

Some of the pyroxene was separated quite readily from the Lynch Creek lava and breccia for analysis. The result of this analysis is listed in Table II together with analyses of similar pyroxenes for comparison.

Table III indicates the calculation of the formula of the pyroxene on the basis of six oxygen atoms.

Using the above analysis the composition of the pyroxene was plotted on the nomenclature diagram illustrated by Poldervaart and Hess (1951). According to this scheme figure 4 indicates that the pyroxene would be classed as a salite which belongs to the diopside - hedenbergite series of clinopyroxenes.

Poldervaart and Hess (1951) state, "In most basalts of oceanic islands and in many other alkalic basalts, orthopyroxene and pigeonite are generally absent. Olivine appears as early phenocrysts and continues to crystallise for a considerable interval before a clinopyroxene separates. When clinopyroxene does appear, it is commonly a member of the diopside - hedenbergite series rather than augite ---- They are

TABLE II - ANALYSES AND OPTICAL PROPERTIES OF PYROXENES

	I	a	b	c
SiO_2	48.53	50.23	45.86	48.77
Al_2O_3	7.10	5.29	8.30	4.18
Fe_2O_3	0.70	1.16	2.08	2.03
FeO	5.71	4.48	7.03	9.34
MgO	15.99	14.74	12.65	12.48
CaO	21.24	20.50	20.23	20.49
Na_2O	n.dt.	0.70	0.68	0.51
K_2O	n.dt.	0.10	0.11	0.02
H_2O+	n.dt.	0.66	0.54	0.98
H_2O-	n.dt.	0.03	0.02	
TiO_2	0.85	0.92	2.34	1.59
P_2O_5	n.dt.	0.05	0.05	nil
MnO	n.dt.	0.25	0.17	0.11
CO_2	n.dt.	0.68	0.20	-
	100.12	99.79	100.26	100.50
Optical Data				
α	1.69(dt. graph.)	1.685	1.707	1.699
β	n.dt.	1.690	1.714	1.706
γ	1.72(dt. graph.)	1.706	1.727	1.722
$\gamma-\alpha$.....	0.030	0.021	0.020	0.023
2V(+)	51°	49°	58°	52°
γ:c	50°	53°	55°	44°
Sp. Gr.	3.307	-	-	-
Atomic %				
Ca	46.7	47.5	48.3	46.8
Mg	42.3	43.4	36.6	34.2
Fe	11.0	9.1	15.1	19.0

I. Pyroxene from Lynch Creek lava, South Queenstown, Tasmania. Anal. B. Scott.
a. Pyroxene from olivine basalt (Lower Carb.) from Old Pallas area, Co. Limerick. Ashby (1946) p.196.
b. Pyroxene from olivine basalt as for (a).
c. Pyroxene from olivine trachybasalt as for (a).

TABLE III - CALCULATION OF FORMULA OF PYROXENE.

Oxides	Weight %	Molecular Proportions	Ionic Ratios	Positive Ions
SiO_2	48.53	0.809	0.809	1.785
Al_2O_3	7.10	0.070	0.140	0.309
Fe_2O_3	0.70	0.004	0.008	0.018
FeO	5.71	0.079	0.079	0.174
MgO	15.99	0.400	0.400	0.883
CaO	21.24	0.380	0.380	0.839
TiO_2	0.85	0.010	0.010	0.022

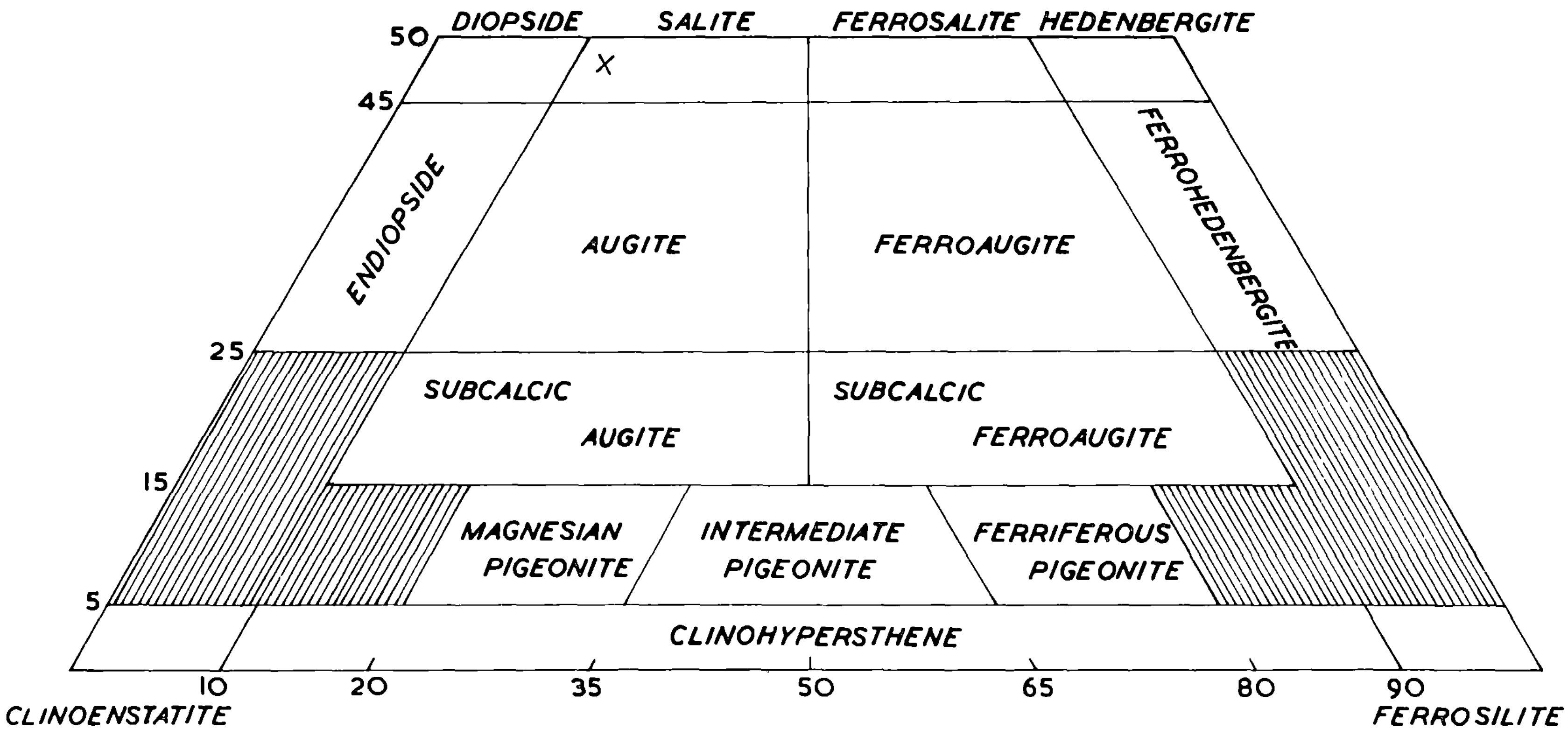
Z	Si	1.785
	Al	0.215
Y	Al	0.084
	Ti	0.022
	Fe'''	0.018
	Fe''	0.174
	Mg	0.883
X	Ca	0.839

i.e. $Z = 2.00$

$XY = 2.020$

or

$$Ca_{0.839}\,(Al,\ Ti,\ Fe''',\ Fe'',\ Mg)_{1.181}\,(Si,\ Al)_2\,O_6$$



NOMENCLATURE OF PYROXENES CRYSTALLIZED FROM BASALTIC MAGMAS (MOLECULAR PER CENT) — AFTER POLDERVAART AND HESS (1951)

Figure 4

diopside - hedenbergite clinopyroxenes (Salites), rich in TiO_2 and the sesquioxides." It seems then that the pyroxene fits well the suite of rocks in which it is found. In the paper on the King Island volcanics the author refers to the similarity of the rocks to the Pacific or Oceanic type.

The stability of the pyroxene is an amazing feature. It has succumbed to alteration in some cases, the most common type of alteration being to chlorite, quartz and calcite but in many instances it has remained unaltered. A suggestion was made (Scott 1951 (a)) that the diopsidic augite may have been immune to alteration because of the similarity of its chemical composition to the invading solutions. However, the other possibility is that this pyroxene has a stable lattice structure.
see E.V. Shannon Proc. U.S. Nat. Museum, vol 66

Because of its freshness there were times when the author began to think of the pyroxene as a metamorphic mineral but the grade of metamorphism which prevailed would not be sufficiently high to cause the formation of a pyroxene. Its particular association with the plagioclase in the King Island lavas is further evidence to support a primary origin.

Iron Ores.

At times it is difficult to distinguish between magnetite and ilmenite. Both seem to be present. The ilmenite often shows skeletal habit and alteration to leucoxene while the magnetite is usually granular and sometimes is altered to limonite.

Haematite is common in the Smithton lavas and appears to be a secondary mineral.

Pyrite is a frequent constituent and is usually in cubic crystals. Sometimes it shows alteration to limonite.

Quartz.

This is a very common constituent of the rocks. Sometimes it occurs as complete replacements of the lava, e.g., the spherulitic quartz rock and at others it occurs as "phenocrysts" in the "porphyries" and is interstitial to the albite laths in the basalts. It is also a common infilling of vesicles and veins.

If any of the quartz is primary it is impossible to distinguish it from the product of silicification.

Chlorite.

Like quartz, this is a very common mineral and is found in most rocks. It occurs as the alteration product of pyroxene, olivine and plagioclase and is a very common constituent in vesicles and veins. There are, no doubt, several varieties of chlorite present as revealed by X-ray powder photography but the most common variety is pennine with its characteristic anomalous interference colours. Another variety is very bright green in colour and the author is inclined to believe it is the nickel bearing variety, garnierite. It is not very common but its presence is soon noted because of the brightness of colour. [illegible]

Variety exists in the pennine. It is usually very pale green to almost colourless and fibrous in form. It is sometimes slightly pleochroic and has very low interference colours. Chlorites tested from the King Island rocks yielded refractive indices $\alpha = 1.591$, $\gamma = 1.594$ and $\alpha = 1.624$, $\gamma = 1.629$. They are optically positive and length slow.

Epidote.

In certain localities this mineral is very abundant while in others it is almost absent. For example, its presence is neglible in the porphyritized lavas along the crest of the geanticlinal structure compared with its abundance in the rocks found on King Island, at Smithton, Leven Gorge, Quamby Brook etc.

It is colourless to pale green. Sometimes it develops as idiomorphic crystals while at others it is finely granular. The epidote quite often shows twinning. Its occurrence is most common in vesicles and veins but it is known as one of the alteration products of the pyroxene and plagioclase.

Tremolite.

Colourless to very pale green tremolite as small needle like crystals which seem to pierce and cut across other minerals, particularly quartz and albite, is very common. Its occurrence in the King Island rocks has been previously described (Scott 1951 (a)). This mode of occurrence holds for other lavas.

Calcite.

Like most of the secondary minerals calcite is found in veins and vesicles and it may be developed between the laths of albite as a replacement product of the pyroxene as in the Montana melaphyre. In the Beaconsfield picrite basalt the calcite pseudomorphs idiomorphic phenocrysts of olivine. Calcite is quite common and when present is usually accompanied by quartz. Quartz-calcite rocks have been observed from Montana and it seems likely that these were originally old lavas.

Prehnite.

Prehnite is quite commonly found in the King Island rocks but apart from its presence as radiating crystals in a few vesicles in lavas from Lynch Creek, South Queenstown, it is lacking elsewhere.

Hydrogrossular.

Apart from a small amount of hydrogrossular in the Smithton lavas where it replaces olivine and its presence in a tuffaceous rock in the bed of the Arthur River where it crosses the Waratah - Corinna Road this mineral seems to be restricted to King Island where it is fairly abundant. A full description of this mineral appears in the King Island paper.

Sericite.

This mineral is fairly common and occurs mostly as the alteration product of the albite although it has been described from vesicles in the King Island pahoehoe lavas.

<u>Sphene.</u>

Granules of sphene are quite commonly scattered throughout the rocks and are usually associated with the chlorite. It seems that they are of secondary origin and have been derived from the break down of the pyroxene or from the alteration of ilmenite.

<u>Hornblende.</u>

No primary hornblende has been found. It is usually idioblastic in form and has developed as "phenocrysts" from the alteration products of augite as previously described from the porphyritized rocks.

It is greenish brown in colour and shows strong pleochroism, X = yellow, Y = greenish brown and Z = brownish green, giving the absorption scheme X<Y<Z. Cleavage is well developed and both simple and multiple twinning may be present also colour zoning. The maximum extinction angle is 24°.

The other form of hornblende is that developed with chlorite as the alteration product of augite between the laths of albite. These two minerals seem to merge imperceptibly into each other.

Biotite.

Like hornblende, no primary biotite has been observed. Very little has been found and then it has been associated with hornblende and chlorite in the porphyritized rocks. Like the hornblende the biotite seems to merge imperceptibly into the chlorite. This effect is most notable when the minerals are in a radiating form.

CHEMICAL COMPOSITION AND NATURE OF THE PARENT MAGMA.

A limited number of chemical analyses ~~were~~ was carried out because of the altered nature of the rocks. Analyses of the King Island rocks, one from Lynch Creek near Queenstown and another from Groom's Slip near Penguin were completed by the author while those of the Smithton rocks, completed by the Geological Survey Laboratory, appear in Bulletin 41.

The similarity of the chemical composition of the rocks is revealed in Table IV and supports the evidence of similarity revealed under the microscope existing between the augite porphyritic rocks of Lynch Creek and Smithton, the pillow lavas of King Island, Penguin and Smithton and the non-porphyritic basalt at Smithton with the basaltic types of King Island and Penguin.

Analyses of the breccias and tuff in Table V indicate that they are closely related to the parent basic magma.

In the majority of rocks titanium is low and this seems to be a characteristic feature of the suite of lavas. Its presence in abundance is dependent upon the occurrence of ilmenite and secondary sphene. The

TABLE IV - ANALYSES OF BASIC LAVAS.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
SiO_2	44.20	45.00	46.53	46.64	46.72	46.88	47.40	48.24	48.35	50.01	50.16	52.61	53.20
Al_2O_3	20.80	24.64	10.51	23.45	18.25	19.04	19.19	17.55	16.82	15.38	18.01	13.03	19.15
Fe_2O_3	9.98	7.58	0.62	9.00	2.38	5.15	1.48	1.05	2.85	4.86	13.98	3.90	7.72
FeO	5.84	3.48	8.27	1.80	7.73	9.03	8.26	7.04	10.21	9.21	4.15	8.48	3.87
MgO	3.18	6.30	17.36	3.26	7.81	5.62	3.60	5.27	4.46	5.85	1.84	5.10	2.89
CaO	10.40	9.07	10.04	10.91	7.86	10.67	11.25	10.43	9.55	6.35	1.40	7.26	1.24
Na_2O	1.71	1.06	1.90	2.09	2.64	2.00	3.40	5.58	3.78	4.77	4.43	5.60	5.17
K_2O	0.36	0.46	0.22	0.50	1.32	0.55	1.31	0.97	0.42	0.40	0.83	0.42	0.58
H_2O+	1.44	3.20	3.71	3.00	0.11	2.00	3.32	2.88	2.52	2.60	2.10	1.65	4.00
H_2O-			0.31		4.43		0.34	0.17	0.32	0.23		0.10	
TiO_2	1.44	0.32	0.21	0.54	0.48	1.48	0.29	0.70	0.78	0.73	2.00	0.72	1.74
MnO	1.06	-	0.16	-	0.07	Tr.	0.13	0.12	0.10	0.21	Tr.	0.19	Tr.
P_2O_5	0.15	0.05	Tr.	0.09	n.dt.	0.13	n.dt.	0.10	n.dt.	0.09	0.25	Tr.	0.30
CO_2	-	-	-	-	-	-	-	0.11	-	0.13	-	0.05	-
S	-	Tr.	-	0.27	-	0.04	-	-	-	-	Tr.	0.08	0.05
	100.56	101.16	99.84	101.55	99.80	100.59	99.97	100.21	99.96	100.82	99.15	99.19	99.91

I Fine grained porphyritic dolerite, Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

II Altered dolerite porphyrite, Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

III Picrite basalt (as lava), King Island. Anal. B. Scott.

IV Altered basic augite porphyrite, Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

V Porphyritic (augite) basic lava, Lynch Creek, South Queenstown. Anal. B. Scott.

VI Fine grained non-porphyritic dolerite, Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

VII Spilite (intergrowth type), King Island. Anal. B. Scott.

VIII Spilite (ophitic type), King Island. Anal. B. Scott.

IX Spilite (pillow lava), Groom's Slip, near Penguin. Anal. B. Scott.

X Spilite (basaltic type), King Island. Anal. B. Scott.

XI Mugearite (reinterpreted as pillow lava), Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

XII Spilite (pillow lava), King Island. Anal. B. Scott.

XIII Mugearite (reinterpreted as pillow lava), Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin No. 41).

TABLE V - ANALYSES OF TUFFS AND BRECCIAS.

	I	II	III	IV
SiO_2	46.60	48.08	49.28	51.14
Al_2O_3	19.23	18.91	13.78	9.01
Fe_2O_3	19.16	21.61	7.12	2.32
FeO	0.26	0.49	5.93	3.99
MgO	4.49	5.07	7.24	12.49
CaO	2.95	2.35	5.81	14.34
Na_2O	3.29	0.67	2.44	1.67
K_2O	0.54	1.20	1.10	0.39
H_2O+	4.06	1.70	4.90	2.64
H_2O-				0.20
TiO_2	-	-	2.20	0.49
MnO	0.22	-	Tr.	0.16
P_2O_5	-	-	0.25	n.dt.
CO_2	-	-	-	0.90
TOTAL	100.80	100.08	100.05	99.74

I Felspathic breccia, Magnet Creek. Anal. Geol. Surv. Lab. Tas. (Bulletin 33).

II Micaceous breccia, Magnet Mine. Anal. Geol. Surv. Lab. Tas. (Bulletin 33).

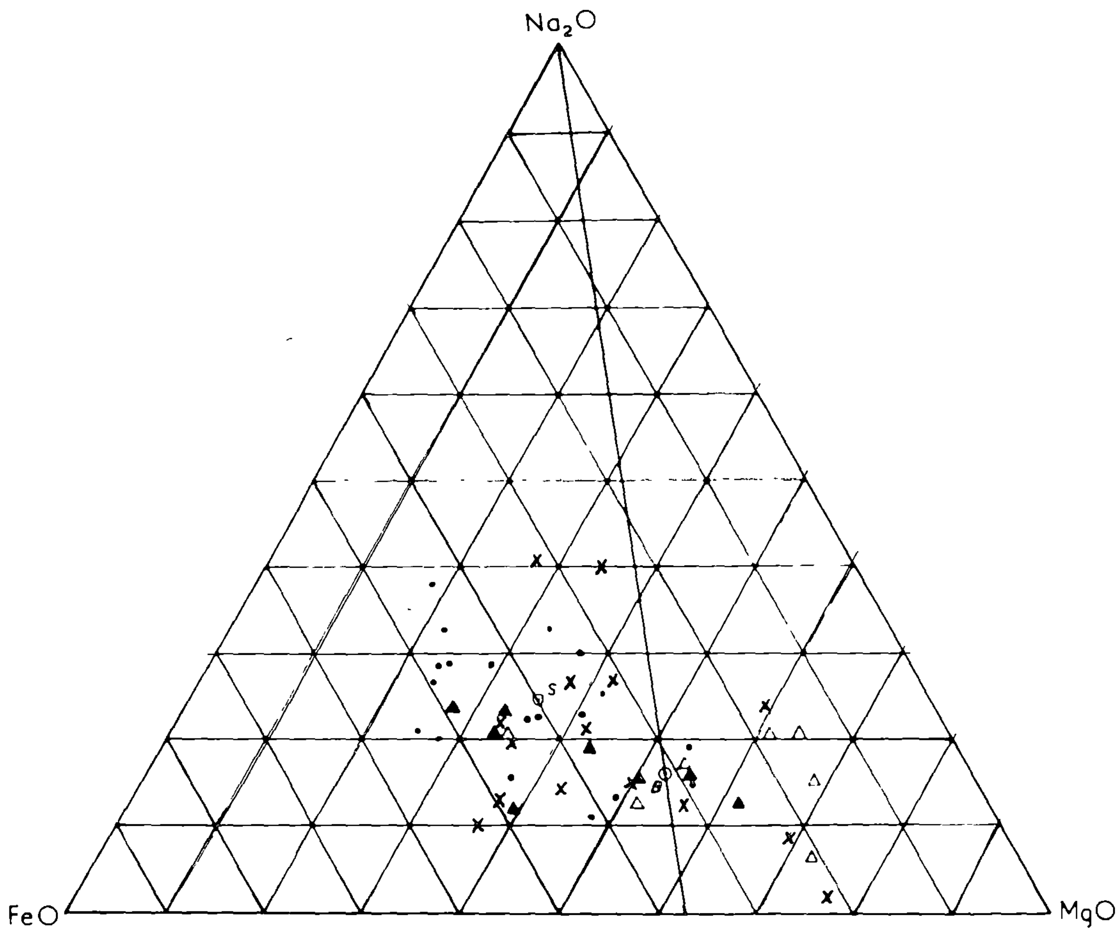
III Dundas breccia, Smithton. Anal. Geol. Surv. Lab. Tas. (Bulletin 41).

IV Tuff between pillows of lava, King Island. Anal. B. Scott.

range in silica is very low, only being in the order of 9%. Alumina is high throughout. With the exception of the porphyritic augite rocks the soda content is high and indicates that the rocks have spilitic affinities. This feature is illustrated by their position on the Na_2O-FeO-MgO triangular diagram (figure 5). In fact, on the West Coast there is the typical spilitic association of spilites, albite diabases, keratophyres, and ultrabasic intrusives.

The molecular percentages of the normative felspars are plotted on a triangular diagram (figure 6).

With the Tasmanian rocks on the two triangular diagrams are plotted groups of rocks of similar age from South Australia and Western Australia. An anomaly appears to exist between the petrography and the interpretations of the Na_2O-FeO-MgO and Or-Ab-An diagrams. Figure 5 would seem to indicate that the majority of Western Australian basic lavas have spilitic affinities and likewise most of the King Island rocks. Although all the King Island lavas and some of the South Australian have been albitized the Western Australian rocks carry plagioclase ranging in composition from andesine to labradorite. However, figure 6, based on the molecular percentages of normative felspar, seems to break the basic



CAMBRIAN LAVAS FROM -

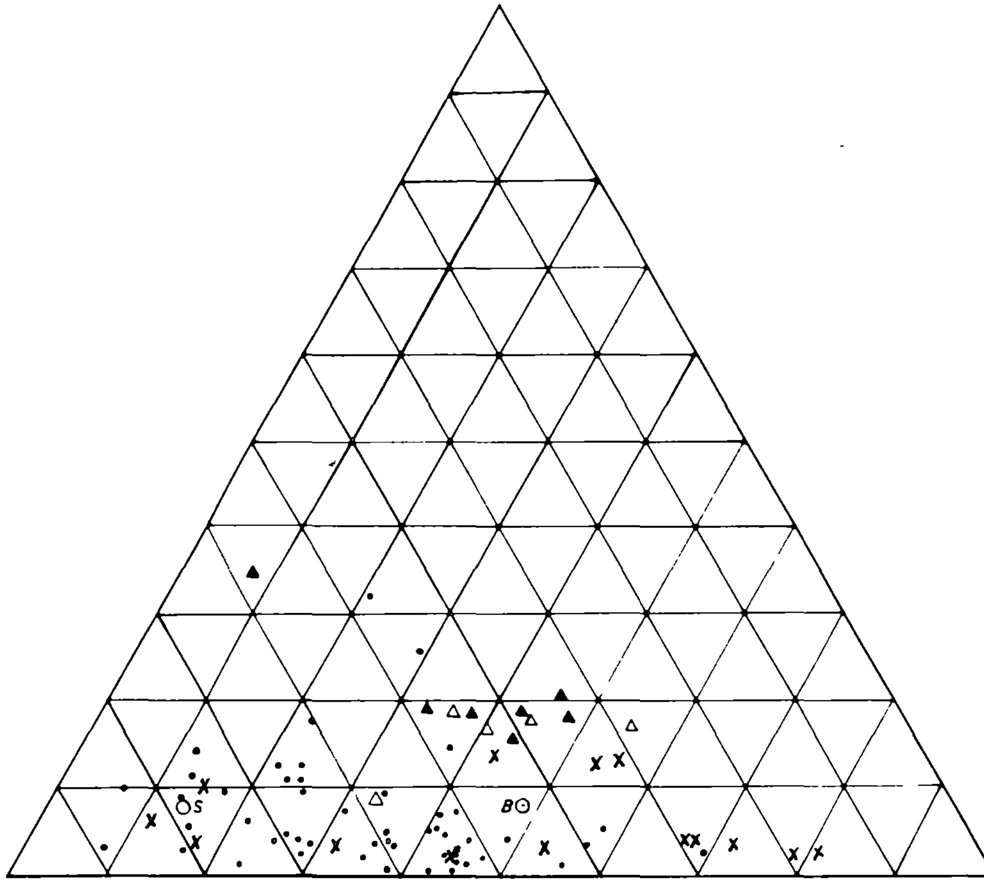
X TASMANIA • SPILITES FROM OTHER PARTS OF THE WORLD

△ SOUTH AUSTRALIA ○S AVERAGE SPILITE

▲ WESTERN AUSTRALIA ○B AVERAGE BASALT

Figure 5

Or



Ab An

Molecular Percentages of Normative Felspars

CAMBRIAN LAVAS FROM —

X *TASMANIA* • *SPILITES FROM OTHER PARTS OF THE WORLD*

△ *SOUTH AUSTRALIA* ○S *AVERAGE SPILITE*

▲ *WESTERN AUSTRALIA* ○B *AVERAGE BASALT*

Figure 6

lavas into two groups - a spilitic and a non spilitic - the Western Australian and South Australian together with several Tasmanian rocks forming the greater part of the latter group. It seems to the writer that diagrams such as figures 5 and 6 are very hypothetical and tend to give false impressions.

Following the scheme of Walker and Poldervaart (1949) of using variation diagrams based on $\frac{FeO + Fe_2O_3}{MgO+FeO+Fe_2O_3}$ instead of silica with the basic oxides to show the differentiation of a basaltic magma a variation diagram was produced for the Tasmanian lavas. Using the $\frac{FeO + Fe_2O_3}{MgO + FeO + Fe_2O_3}$ X-100 ratio as an index the rocks fall into the following groups:

1. 33.86 - the picrite basalt.
2. 55-65 - which includes the porphyritic augite basalts.
3. 70-80 - into which the majority of the rocks fall.
4. 80 + - which includes the "mugearites" from Smithton.

The diagram (figure 7) indicates that in general there is very little variation apart from the soda which does not seem to obey any rule.

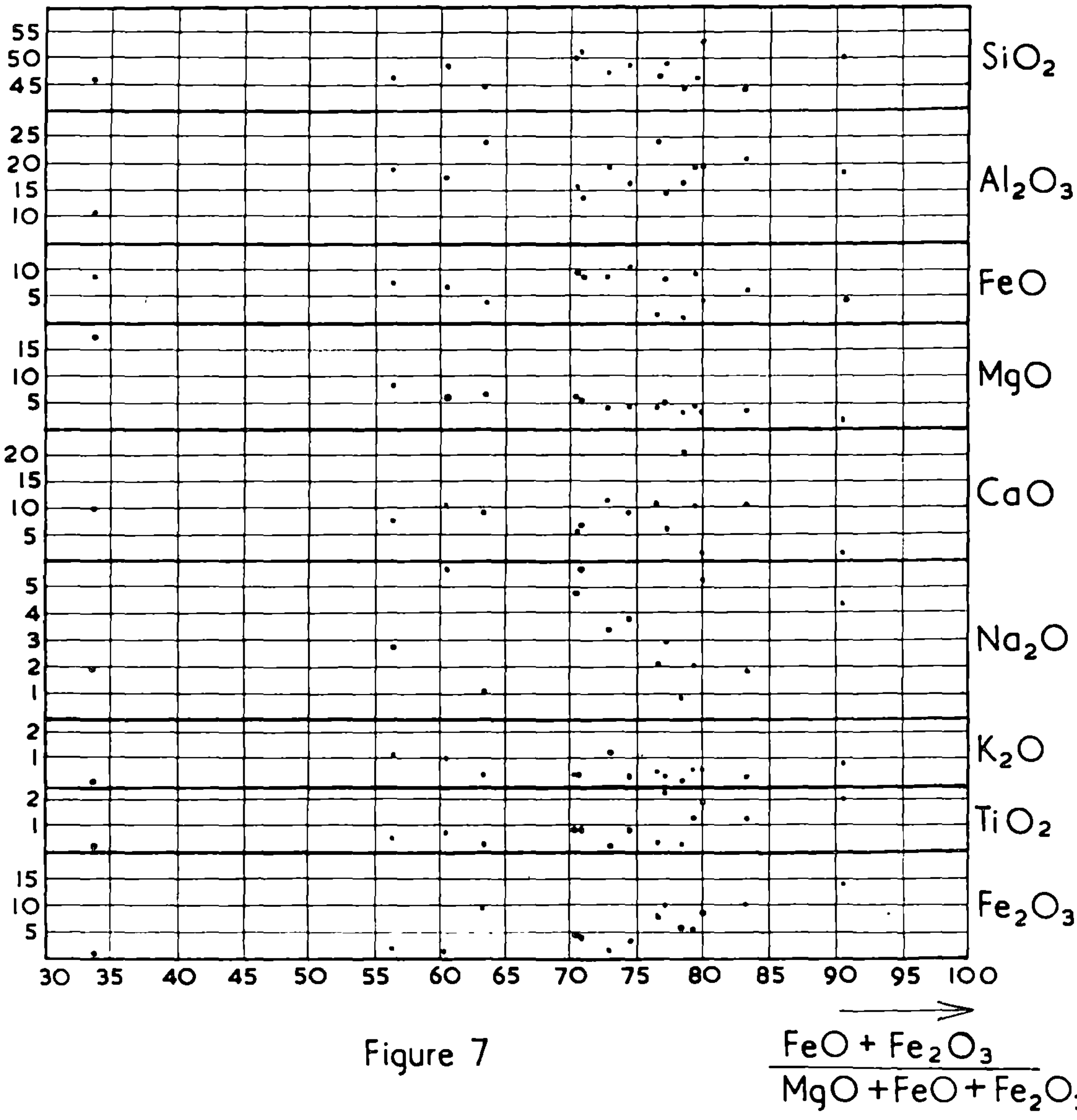


Figure 7

Chemical Variation of the Tasmanian 'Spilitic' Magma

It was suggested in a previous section that the high soda content in these basic lavas is due to a secondary origin and that the original lava was a basalt. The soda content is ignored for the time being and the remainder of the chemical composition of the lavas is examined critically to see if it is possible to determine whether the parent basalt was of the olivine variety or tholeiitic.

Listed in Table VI are the average analyses of a plateau basalt (tholeiite), olivine basalt, spilite and the Tasmanian lavas under study. Compared with the average tholeiite, olivine basalt and spilite the Tasmanian rocks are far higher in alumina and very deficient in titania while magnesia is low compared with that of the olivine basalt. No matter with what type of basalt these rocks are compared there are always anomalies. They do not seem to fit with ease into one particular group.

Because of the altered nature of the rocks it is very difficult to determine the differentiated members of the suite. From the fragmentary evidence available it seems that they range from picrite basalt (King Island), basalt with little olivine (Smithton and Montana), olivine

TABLE VI - AVERAGE ANALYSES OF BASALT TYPES

	I	II	III	IV
SiO_2	48.15	51.22	48.80	49.58
Al_2O_3	18.14	13.66	15.98	13.19
Fe_2O_3	5.50	2.84	3.59	2.40
FeO	6.72	9.20	9.78	9.49
MgO	5.41	4.55	6.70	8.30
CaO	8.16	6.89	9.38	10.69
Na_2O	3.42	4.93	2.59	2.25
K_2O	0.66	0.75	0.69	0.55
H_2O+ / H_2O-	2.94	1.88	1.80	
TiO_2	0.95	3.32	2.19	3.17
MnO	0.16	0.25	0.17	0.12
P_2O_5	Tr.	0.29	0.33	0.26
CO_2	Tr.	0.94		

I Average Tasmanian Basalt - average of 13 analyses from Table IV.

II Average Spilite according to Sundius (1930).

III Average Tholeiite according to Daly recorded in Wahlstrom (1950).

IV Average Olivine Basalt - average of 11 olivine basalts, from Hawaii calculated as water free according to Daly recorded in Turner & Verhoogen (1951).

free basalt (most localities), porphyritic basalt (most localities), trachybasalt (?) (Smithton and Leven Gorge), and keratophyre without trachytic fabric indicating that the original rock may have been rhyolite (Queenstown, Read-Rosebery District etc.). It must be remembered that no original olivine remains. The inference of the original presence of olivine is based on the occurrence of pseudomorphs in the rock. Such a suite of differentiate products is indicative of olivine basaltic parentage.

The pyroxene of the suite is diopsidic and as such shows affinities to the olivine basalts. Not one of the rocks analysed by the author is oversaturated. All are undersaturated and show quite high percentages of normative olivine. However, comparing the individual analyses (see Table IV) the higher SiO_2 in general and the lower MgO contents indicate tholeiitic affinities. In either case, Al_2O_3 is too high and TiO_2 too low.

Tilley (1950) states "The basaltic rocks met with in the orogenic belts include a wide variety of types, those most characteristically developed showing a high alumina content, and a strongly porphyritic character is furthermore common. Some of the types are difficult to classify, including those designated as andesitic basalts." A truer description could not be written for the Tasmanian Cambrian lavas. He mentions that in orogenic regions there are also basalts which do not fall into the categories of normal tholeiites or olivine basalts. These are rich in alumina and non-porphyritic and have been described from Yellowstone National Park, Lassen Peak district and about 40 miles north of this district on the Medicine Lake Highland of the Modoc Lava Quadrangle of California where they form the widespread flows of the Pliocene Warner and later Modoc basalts. It is interesting to note that the Tasmanian lavas fall into this category. Here the porphyritic as well as the non-porphyritic are rich in alumina.

The following Table VII is reproduced from Tilley (1950, p.55) and to it are added the average of 5 analyses of the non-porphyritic basalts of Tasmania which the author herself completed and the average of all available analyses of the Tasmanian lavas. $CaO + Na_2O$ totals are added. The similarity of the Tasmanian rocks with those given by Tilley is very noticeable. Certainly the Na_2O content is much higher but assuming that Na_2O replaces the CaO of the felspar the total $CaO + Na_2O$ in all

TABLE VII - ALUMINA-RICH BASALTS.

	I	II	a	b	c	d
SiO_2	49.3	48.2	48.2	47.9	50.0	51.9
Al_2O_3	16.4	18.1	18.6	18.9	18.0	14.3
Fe_2O_3	2.8	5.5	0.8	1.2	9.0	14.3
FeO	8.6	6.7	7.9	8.6		
MgO	4.9	5.4	9.1	7.8	5.0	4.0
CaO	9.0	8.2	11.2	10.5	10.0	8.4
Na_2O	4.6	3.4	2.5	2.4	2.5	2.9
K_2O	0.7	0.7	0.2	0.2	0.4	1.6
TiO_2	0.6	1.0	0.9	1.4	1.0	2.5
Ca + Na_2O	13.6	11.6	13.7	12.9	12.5	11.3

I Average of 5 non-porphyritic Cambrian basalts from Tasmania.

II Average of 13 Cambrian basalts from Tasmania.

a. Average of 3 subophitic basalts, Medicine Lake Highland, California (data from Anderson 1941, p.387).

b. Skaergaard gabbro - chilled marginal phase.

c. Porphyritic Central type basalt, Mull.

d. Average of Miocene Columbia plateau basalts (Waters, in Anderson 1941, p.404).

is very similar.

It seems, then, that the parent magma of the Tasmanian Cambrian lavas approximated the Porphyritic Central type basalt of Mull. According to the authors of the Mull Memoir this Porphyritic Central type basalt was derived from an olivine basaltic type by the separation and accumulation of crystals of calcic plagioclase. This mode of origin would fit similar rocks in Tasmania but high alumina is present in the whole suite from picrite basalt upwards. Unless a secondary origin for the alumina is postulated an origin has to be found for an aluminous magma which will also account for the presence of high alumina throughout and not in one differentiated phase.

cf Kennedy 1929 Brown 1928

The Al_2O_3 and TiO_2 contents are in keeping with those of intermediate magmas (andesitic) so it may be possible that the Tasmanian lavas are basic differentiates of an intermediate magma which could have been derived from basalt, with close affinities to an olivine variety, by contamination at depth with the sial. Tilley (1950) thinks that an intermediate magma may be derived from a normal tholeiitic magma which has been contaminated with sialic material. He is of the opinion that the tholeiitic magma is the parent magma and olivine basalts are derived from this by differentiation and intermediate (andesitic) magmas by sialic contamination. Turner and Ver~~b~~hoogen (1950) derive the magmas from which spilites are formed from an olivine-basalt magma. They state, "Differentiation of this magma, assimilative reaction with rocks situated in the basal levels of the geosyncline, concentration of magmatic water rich in soda, and chemical activity induced by entrapped sea water and rising connate waters squeezed up from deeply buried sediments, are all factors of possible significance in evolution of spilites and keratophyre".

Such an origin (i.e. sialic contamination) may fit the Tasmanian rocks but these were erupted during volcanic activity which took place throughout Australia in Cambrian times. If the high alumina is indigenous to the magma then surely the basalts derived from the same magma but poured out elsewhere in Australia should be are also rich in Al_2O_3 unless of course local conditions at the base of the sial during geosynclinal deposition were such as to provide a special alumina rich magma. In Tables VIII and IX are listed analyses of the South Australian and Western Australian lavas of comparable age.

TABLE VIII - ANALYSES OF PRE-CAMBRIAN AND CAMBRIAN BASIC ROCKS FROM SOUTH AUSTRALIA.

	I	II	III	IV	V	VI	VII
SiO_2	48.46	47.75	45.52	49.29	50.63	47.20	49.40
Al_2O_3	13.76	12.77	14.39	18.81	16.30	14.65	14.42
Fe_2O_3	6.38	7.22	5.21	3.57	5.34	11.55	2.75
FeO	3.01	4.38	6.79	7.78	6.46	3.71	8.87
MgO	6.94	9.92	12.68	3.28	6.62	6.61	7.38
CaO	5.00	5.79	6.22	9.25	7.65	5.39	11.75
Na_2O	3.44	3.46	1.68	3.07	3.22	3.43	2.72
K_2O	1.89	0.81	1.38	2.10	1.69	2.76	0.38
H_2O+	3.55	3.38	3.91	1.07	0.89	2.46	1.36
H_2O-	0.01	0.43	0.88	0.20	0.14	0.49	0.12
CO_2	0.26	1.98	-	Tr.	0.80	0.08	-
TiO_2	1.53	1.65	1.46	2.17	nil	1.80	1.02
P_2O_5	0.28	0.19	0.13	-	-	0.37	0.06
MnO	0.08	0.28	0.22	-	-	0.04	n.dt.
	99.59	100.01	100.47	100.59	99.74	100.54	100.23

I Melaphyre, Wooltana. Anal. W.S. Chapman (Mawson, 1926).

II Olivine diabase, Wooltana. Anal. A.R. Alderman (Mawson, 1926).

III Optic olivine diabase, Wooltana. Anal. A.R. Alderman (Mawson, 1926).

IV Olivine diabase. Anal. W.N. Benson (Benson, 1909)

V Gabbro diabase. Anal. W.N. Benson (Benson, 1909).

VI Melaphyre, Oraporinna. Anal. E.G. Robinson (Mawson 1942).

VII Metadolerite, Blinman. Anal. R.H. Jones (Mawson, 1942).

TABLE IX - ANALYSES OF PRE-CAMBRIAN AND CAMBRIAN BASALTS FROM WESTERN AUSTRALIA.

	I	II	III	IV	V	VI	VII
SiO_2	50.00	51.80	53.95	54.40	52.58	52.67	50.50
Al_2O_3	15.13	18.14	15.98	14.34	10.56	14.34	14.25
Fe_2O_3	3.06	2.45	2.99	8.60	7.10	2.37	0.58
FeO	6.07	6.61	8.49	5.32	9.12	6.95	11.36
MgO	8.33	3.98	3.95	3.44	3.62	7.32	5.01
CaO	9.10	8.50	5.35	7.25	5.95	6.99	10.15
Na_2O	2.59	2.72	3.10	2.27	3.53	3.20	2.58
K_2O	1.81	1.89	2.00	1.95	2.80	1.92	1.39
H_2O+	0.91	1.04	1.25	0.34	1.33	1.99	0.35
H_2O-	0.50	1.05	0.65	0.56	0.56	0.38	0.62
CO_2	0.20	0.05	Tr.	0.20	nil	0.06	1.83
TiO_2	1.25	0.75	1.00	1.25	2.62	1.02	1.22
P_2O_5	0.55	0.41	0.68	0.30	n.dt.	0.09	0.05
MnO	0.17	0.08	0.17	0.21	0.42	0.39	0.28
	99.67	99.47	99.56	100.43	100.19	99.69	100.17

I Olivine basalt, E. Kimberley. Anal. A.B. Edwards (Edwards and Clarke, 1940).

II Felspar basalt, E. Kimberley. Anal. A.B. Edwards (Edwards and Clarke, 1940).

III Argyle basalt, E. Kimberley. Anal. A.B. Edwards (Edwards and Clarke, 1940).

IV Quartz basalt, S. of Hardman Range, Northern Territory. Anal. A.B. Edwards (Edwards and Clarke, 1940).

V Basalt, nr. Wyndham, Kimberley District. Anal. C.G. Gibson (Edwards and Clarke, 1940).

VI Subophitic basalt, S. of Hardman Range, Northern Territory. Anal. R.W. Fletcher (Edwards and Clarke, 1940).

VII Aphanitic basalt, lat. 16° 21', long. 128°. Anal. A.B.Edwards (Edwards and Clarke, 1940).

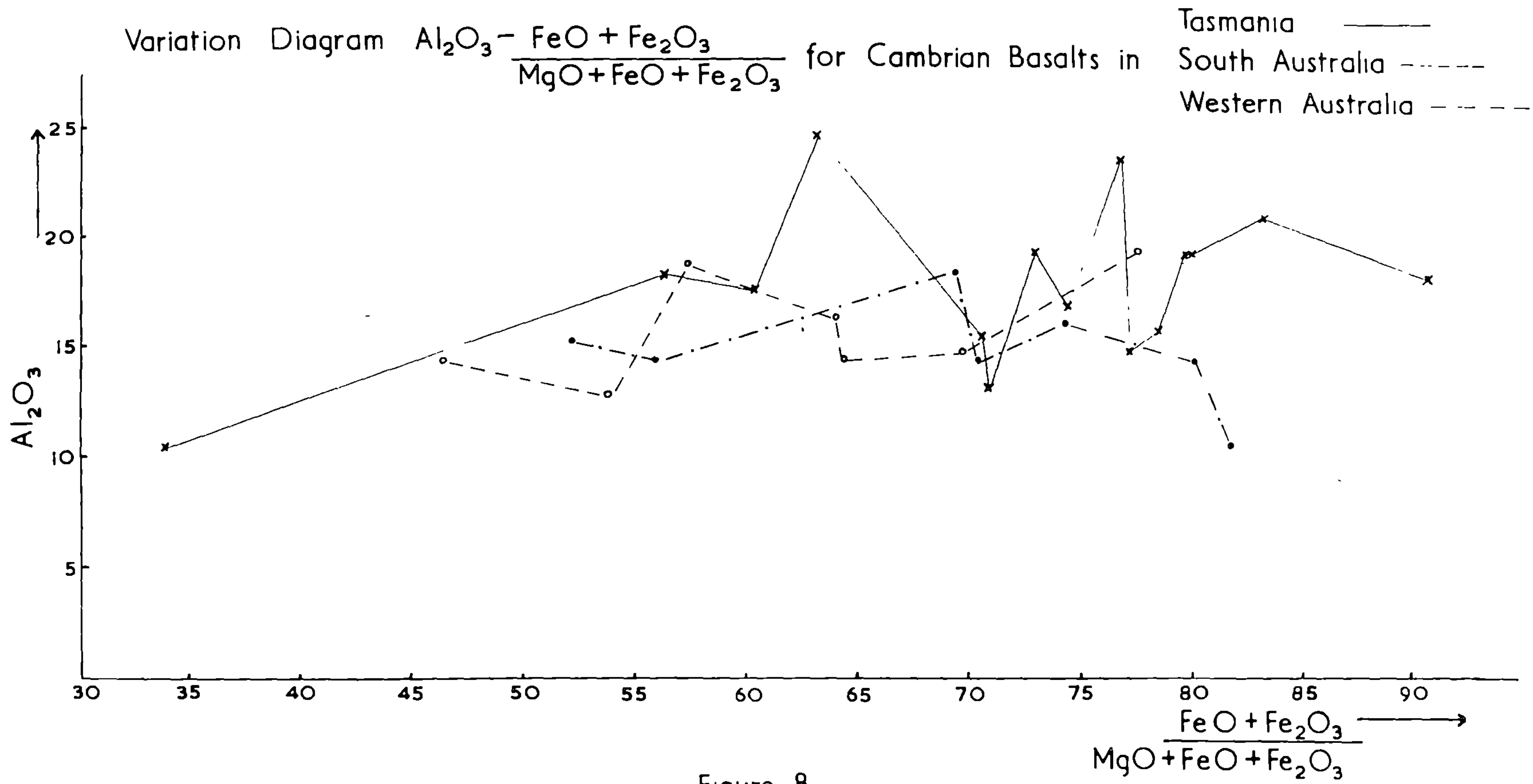
Rocks from both these states are considered to have tholeiitic affinities, although small amounts of olivine basalt are associated. Spry (1950) indicates that some of the South Australian basalts, although not true spilites have spilitic affinities.

Study of the analyses indicates that the alumina content is variable but figure 8, a variation diagram of Al_2O_3 plotted against $\frac{FeO+Fe_2O_3}{MgO+FeO+Fe_2O_3}$ brings out an interesting fact. The Al_2O_3 content is persistently higher in the Tasmanian rocks and persistently lower in the Western Australian. In the South Australian lavas the Al_2O_3 though variable is intermediate. The high Al_2O_3 in the South Australian rocks always seems to be in those which have suffered most hydrothermal alteration.

The $Al_2O_3 - \frac{FeO+Fe_2O_3}{MgO+FeO+Fe_2O_3}$ contents of the average analyses of the three groups of rock were calculated and the results are as follows:

	Tasmania	South Australia	South Australia recalculated	Western Australia
$\frac{FeO+Fe_2O_3}{MgO+FeO+Fe_2O_3}$	69.31	60.83	69.31	69.46
Al_2O_3	18.14	15.73	17.93	14.68

It seems, then, that the presence of alumina is



Variation Diagram $Al_2O_3 - \frac{FeO + Fe_2O_3}{MgO + FeO + Fe_2O_3}$ for Cambrian Basalts in
Tasmania
South Australia
Western Australia
Al_2O_3
25
20
15
10
5
30
35
40
45
50
55
60
65
70
75
80
85
90
$\frac{FeO + Fe_2O_3}{MgO + FeO + Fe_2O_3}$

Figure 8

very closely allied to the amount of hydrothermal alteration and the tectonic environment during eruption. Perhaps the alumina is secondary. This suggestion is supported by the chemical composition of the ultrabasic rocks given in Table X. The presence of such an extraordinarily high Al_2O_3 content in such rocks is remarked upon elsewhere in this thesis. If these analyses are correct then the only way to account for the Al_2O_3 is to assume it is secondary. It is difficult to postulate the formation of an ultrabasic magma so rich in Al_2O_3 by crystal fractionation even from a magma rich in that constituent. For the more acid differentiates to be still rich in Al_2O_3 the parent magma must have to be phenomenonally high in alumina.

All the available evidence points to a secondary origin for the excess alumina and this origin must be closely linked with that of the Na_2O and SiO_2. It is related to geosynclinal orogeny which is dealt with in a later section. When the petrography is considered, the only minerals which could absorb the extra alumina are the secondary minerals chlorite, hornblende, epidote and prehnite.

TABLE X -- ANALYSES OF ULTRABASIC ROCKS.

	I	II	III	IV	V	VI
SiO_2	33.56	35.39	36.60	45.36	53.60	55.16
Al_2O_3	20.94	16.71	19.89	16.92	2.34	3.50
Fe_2O_3	10.71	9.54	19.51	11.23	10.86	10.70
FeO				0.19	-	
MgO	17.81	25.32	12.31	14.92	25.42	28.05
CaO	nil	Tr.	1.42	3.15	1.58	nil
Na_2O	-	-	-	0.21	0.85	
K_2O	-	-	-		nil	
H_2O	14.84	12.44	10.38	8.36	4.90	
MnO				0.44		
Mg/Fe	3.0	4.6	1.1	2.3	4.0	2.0

I Serpentinized peridotite, Bald Hill. Anal. Geol. Surv. Lab. Tas. (Bulletin 32, p.22).

II Serpentinized peridotite, Riley Ck., Wilson River District. Anal. Geol..Surv. Lab. Tas. (Bull. 32, p.22).

III Serpentinized peridotite, Bald Hill. Anal. Geol. Surv. Lab. Tas. (Bulletin 32, p.24).

IV Hypersthenite, Old Jasper Mine, nr. Waratah. Anal. Geol. Surv. Lab. Tas. (Bulletin 33, p.42).

V Altered pyroxenite (hypersthene), Mt. Bischoff, Waratah. Anal. Geol. Surv. Lab. Tas. (Bulletin 34, p.86).

VI Bronzitite, Jones' Ck., Bald Hill. Anal W.D. Reid, Geol. Surv. Lab. Tas. (Bulletin 32, p.26).

The parent magma of the Tasmanian rocks seems to have closer affinities to an olivine basalt but at the same time is not far removed from a tholeiitic magma which was probably the parent magma of the Cambrian lavas in general. The Tasmanian magma is probably a differentiate from the tholeiitic type but sufficient evidence is not available to support this suggestion. However, the Tasmanian Cambrian basalts do indicate that it is unlikely that three basaltic magmas - olivine basaltic, tholeiitic and spilitic - exist independently.

DISTRIBUTION OF SIMILAR VOLCANIC ROCKS IN OTHER LOCALITIES.

Evidence revealed in all states of Australia indicates that volcanic activity was a general feature throughout the Cambrian period. Based on existing correlations it seems that in some states, e.g., South Australia, New South Wales and Western Australia, vulcanicity commenced in upper Pre-Cambrian times. However, it has been suggested by Carey and Scott (1952) that part of the Upper Adelaide System (Upper Pre-Cambrian in age) may possibly be Cambrian. If this suggestion proves correct then the volcanics associated with the Nullagine Series in Western Australia and the Torrawangee Series in New South Wales which have been correlated with the Adelaide system will be classed as Cambrian also.

According to Professor Carey's reconstruction of Gondwanaland a correlation of the rocks of the Pretoria Series of the Transvaal System of South Africa with those of Cambrian age in Tasmania is suggested. The distribution of late Pre-Cambrian and Cambrian volcanics in Australia and South Africa is shown on a reconstruction of Gondwanaland. (See figure 11). Even Mawson (1946) states "A comparison with the Pre-Cambrian record of South Africa is convincing that this division of the

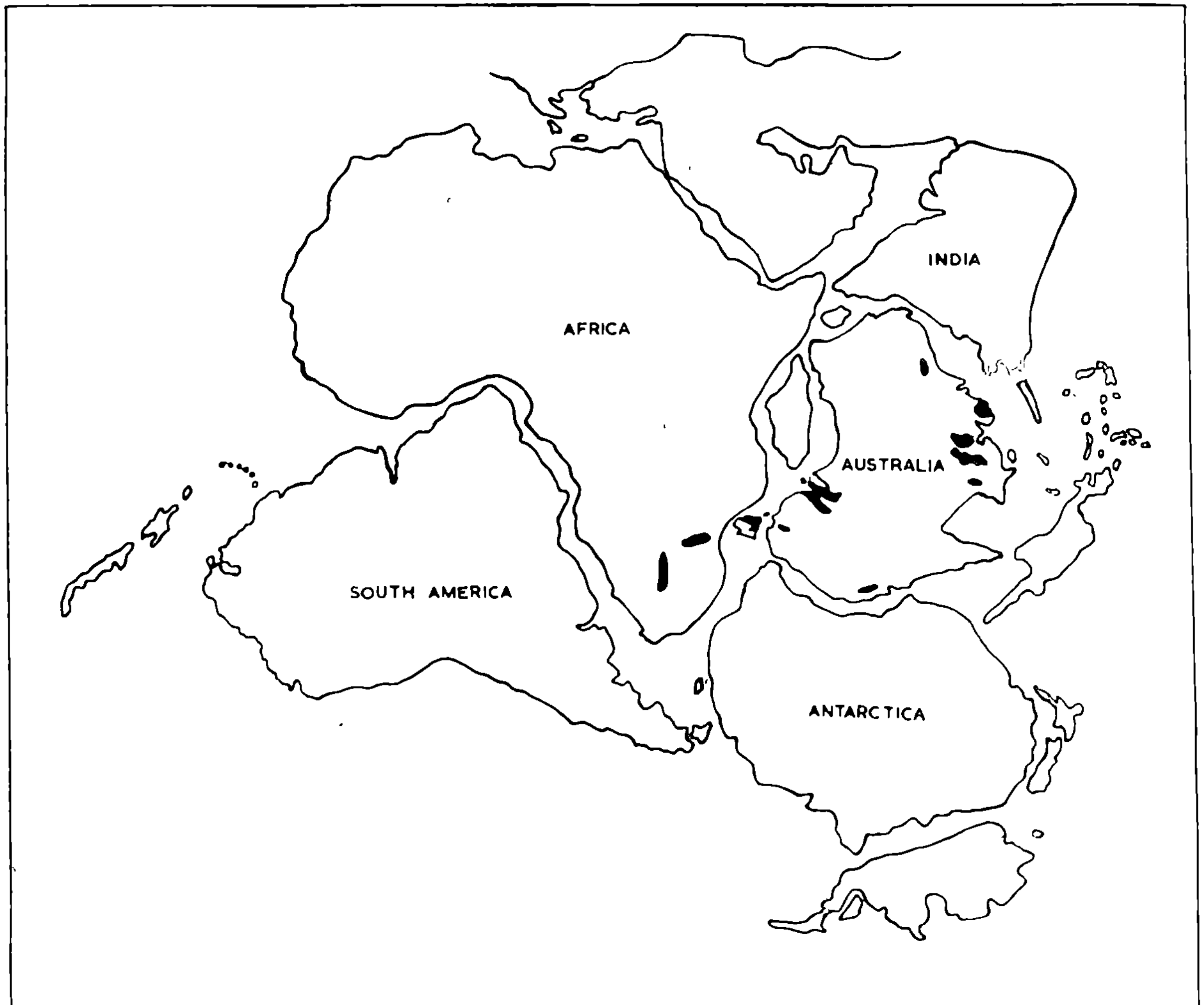
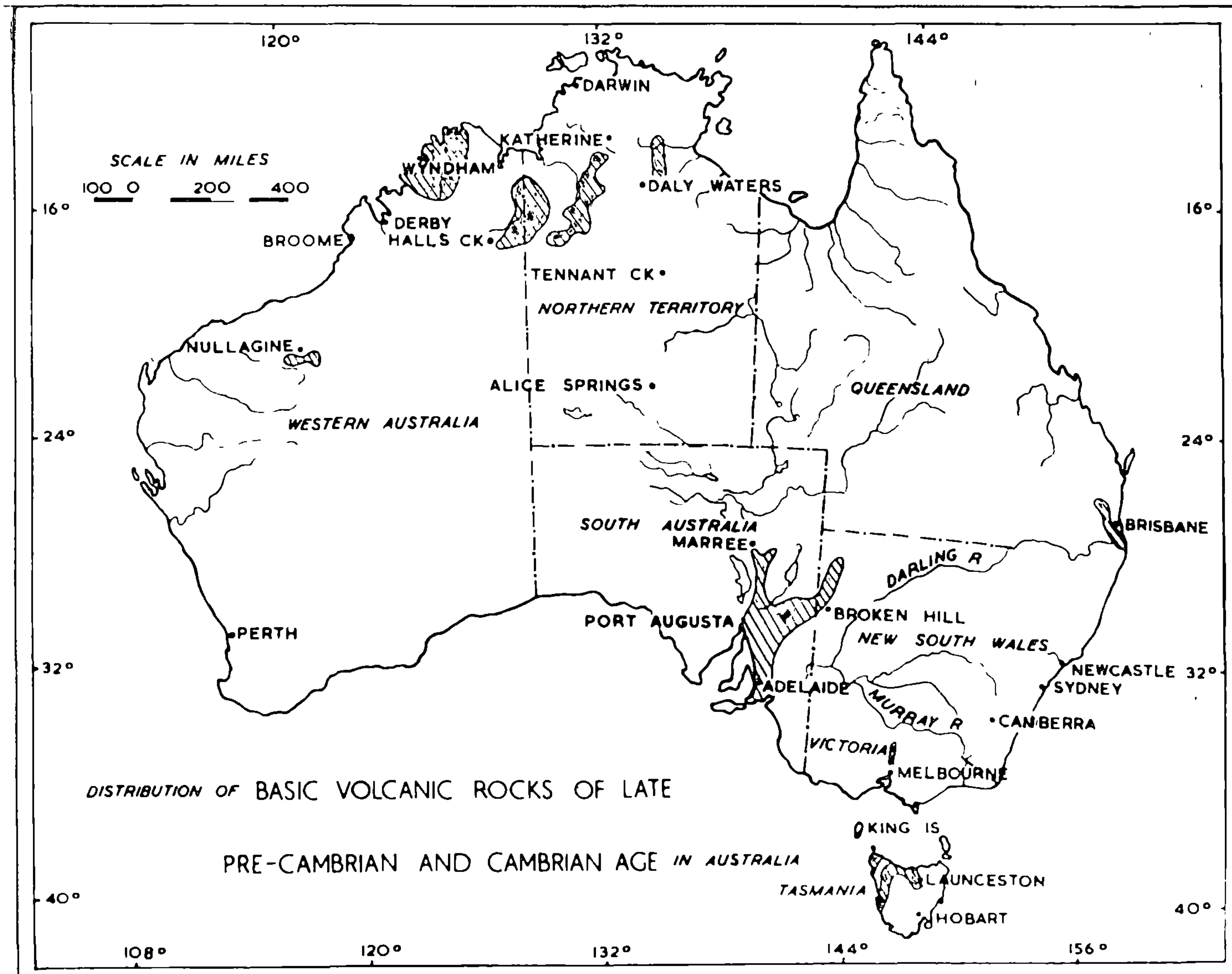


Figure 11

GONDWANALAND — *A RECONSTRUCTION AFTER PROF S W CAREY*

DISTRIBUTION OF LATE PRE-CAMBRIAN AND CAMBRIAN VOLCANIC ROCKS



120°
132°
144°
DARWIN
KATHERINE
WYNDHAM
SCALE IN MILES
100 0 200 400
DALY WATERS
16°
16°
DERBY
HALLS CK
BROOME
TENNANT CK
NORTHERN TERRITORY
NULLAGINE
ALICE SPRINGS
QUEENSLAND
WESTERN AUSTRALIA
24°
24°
SOUTH AUSTRALIA
MARREE
BRISBANE
DARLING R
PORT AUGUSTA
BROKEN HILL
PERTH
NEW SOUTH WALES
32°
NEWCASTLE 32°
SYDNEY
ADELAIDE
MURRAY R
CANBERRA
VICTORIA
MELBOURNE
DISTRIBUTION OF BASIC VOLCANIC ROCKS OF LATE
PRE-CAMBRIAN AND CAMBRIAN AGE IN AUSTRALIA
KING IS
LAUNCESTON
TASMANIA
40°
40°
HOBART
108°
120°
132°
144°
156°

Figure 9

Australian record has its equivalent in the Transvaal System and extensions of the latter in other areas of the South African Union. The detail of the South African succession bears a broad general correspondence to that existing in Australia. Thus the Daspoort Glacial Horizon, the Lower Griquatown Tillite and the Numees Tillite (all apparently records of the same ice age) are broadly equivalent to the Australian Sturtian Tillite. The underlying dolomites and the overlying volcanics are a feature of the sequence in both cases".

Out of interest slides of some of the Ongeluk lavas were examined for comparison. Brief descriptions are given below under the heading of South Africa.

Brief descriptions of the distribution and nature of the volcanics from other states of Australia and South Africa are also given below.

Victoria.

Twelvetrees (1913) mentions the similarity of the porphyroids of the West Coast of Tasmania to the Heathcotian rocks in Victoria. Dr. Thomas, Chief Government Geologist in Victoria, who for a time was Government Geologist in Tasmania and knows both suites of rock intimately is convinced of their similarity. Under Dr. Thomas' guidance as to the best exposures in the field, the author in the company of Professor S.W. Carey and Dr. M.D. Garretty inspected some of the rocks. On seeing them, all were immediately impressed by the similarity of these to those in Tasmania. As well as inspection in the field the author examined hundreds of slides of the Heathcotian "diabase" in the Geology Department of the University of Melbourne. Again the similarity was most striking.

The chief development of the Heathcotian Series is along a submeridional belt or axis which extends for about 70 miles from about Colbinabbin through Heathcote to Mt. William, the Kilmore Gap and Monegetta and in the Howqua River District where the Series occupies two sub-parallel belts of unequal size with a general north west -- south east trend. The western belt widens southwards towards the Jamieson River.

The Series consists of basic tuffs, agglomerates and lavas with basic intrusive rocks which may be related to the effusive types. Individual lava flows vary up to 200 feet in thickness. These volcanic and intrusive rocks have been called "diabases". The rocks are chiefly of submarine volcanic origin and are of spilitic affinities. Associated with the basic rocks are masses of fine-grained granodiorite or microgranite, diorite and porphyrite. Skeats (1908) regarded them as intrusive rocks possibly comagmatic with the basic rocks. However, after experiencing the fantastic changes which have taken place in the Tasmanian basic volcanics giving rise to local development of "keratophyres" and felsites, rocks containing almost 100% silica, granite, granite porphyries, quartz and quartz felspar porphyries, syenite and syenite porphyries etc., the author is inclined to believe that similar changes have brought about the development of these "pseudo" intrusive rocks by metasomatism. In the limited number of exposures seen the basic rocks seemed to grade imperceptably into the acid. Also it is possible to find material in the field which shows gradations, even in a hand specimen, from a syenite to an albite epidote rock both riddled with a micrographic intergrowth of quartz and albite. Like the Tasmanian rocks the Heathcotian diabases have been silicified and converted in parts to jasperoid material. Associated with the diabases are black radiolarian cherts.

The Heathcotian series passes conformably into Middle Cambrian beds, fine-grained fossiliferous black mudstones with volcanic tuffs and breccias and with a small proportion of chert-bands. It is in these beds that fossils are most abundant particularly hydroids, trilobites and brachiopods which have definitely dated the rocks and tied them palaeontologically to the Tasmanian Dundas Group.

The petrology of the diabases is very complex and is being done in detail by Dr. Tattam of the University of Melbourne so the author does not wish to attempt a description in a few pages.

<u>South Australia.</u>

In this State basalts and dolerites associated with agglomerates, breccias and tuffs occur throughout the Adelaide System of Upper Pre-Cambrian Age. The best occurrences are along the Flinders Ranges at Oraparinna, Wooltana, Paralana, Blinman and Hawker. From the last mentioned locality Spry (1951) records only volcanic necks or feeder pipes. No flows have been observed.

In view of recent research on these rocks, their stratigraphical position indicated in the existing literature is incorrect. Mr. A.H. Spry (personal discussion) suggests the following time correlations between the South Australian basalts and the formations of the Adelaide System:

Stratigraphic Sequence	Volcanics.
Chocolate Beds.	
Brighton Limestone.	
Tapley Hill Slates.	
Sturt Tillite.	Blinman Basalts.
Belair and Mitcham Group.	Wooltana Basalt.
Glen Osmond Slates.	
Stoneyfell Quartzite.	
Castambul Dolomite.	Arkaroola, Oraparinna and possibly the Hawker Basalts.
Aldgate Sandstone	

Mawson (1926) regarded the Wooltana basalts as being closely associated with the Sturtian tillite and thought the volcanic activity was either contemporaneous with the glaciation or preceded it with no great intervening time break. It is interesting to note that the volcanics in Tasmania bear the same relationship to the tillite.

These basic rocks include both compact and amygdaloidal fine grained melaphyres (basalts) and dolerites which have suffered to varying degrees such changes as uralitization, saussuritization, epidotization, chloritization and some albitization. The rocks range in grainsize from very fine grained to very coarse grained, in fact almost gabbroic. Some of the dolerites were olivine bearing, the olivine being entirely altered to serpentine.

The author examined many slides of the South Australian basalts and dolerites during a visit to Adelaide. Petrographically these old basic rocks appear similar to the Tasmanian but most of the felspar in the South Australian lavas has not been albitized. Some fresh pyroxene of the augite pigeonite series still remains but usually it has been altered to actinolite, chlorite and epidote. A relative abundance of iron ore is scattered throughout the rocks and calcite is a common constituent.

Mawson and Dallwitz (1944) describe quartz keratophyres from an area in South-East South Australia which extends in a north south direction for about 25 miles from

Papineau Rocks (21 miles E.N.E. of Kingston) to Didicoolan. At Didicoolan these keratophyres have suffered a considerable degree of metamorphism under shearing stress which has reduced them to porphyroids. In hand specimen they are light to dark grey in colour and contain sparce crystals of felspar in a felsitic groundmass. Under the microscope the phenocrysts are seen to be albite and at times have a glomeroporphyritic texture. The groundmass is very fine grained and consists of quartz, felspar, epidote, chlorite, iron ore and leucoxene. At Marcollat the rock is diopside bearing and strangely enough the diopside has the same optical properties as the diopsidic augite from Tasmania. The authors correlate them with the Porphyroid Series of Tasmania. They say "Thus there is good reason to regard the quartz keratophyres and porphyroids of south eastern South Australia as equivalents of the Porphyroid Series of Tasmania and probably of Middle Cambrian age".

Listed below are analyses of the South Australian keratophyres and a "porphyroid" from Tasmania. (Table XI).

<u>Western Australia.</u>

In this State volcanic activity began in Upper

TABLE XI - ANALYSES OF SOUTH AUSTRALIAN KERATOPHYRES AND A "PORPHYROID" FROM TASMANIA.

	I	II	III
SiO_2	76.40	75.22	75.73
Al_2O_3	11.94	12.29	12.70
Fe_2O_3	1.28	1.25	2.25
FeO	1.33	1.73	
MnO	0.09	-	-
MgO	0.39	0.28	0.60
CaO	1.30	1.38	2.00
Na_2O	5.50	6.13	3.48
K_2O	0.69	0.48	2.04
H_2O+	0.57	0.75	1.20
H_2O-	0.08	0.09	
TiO_2	0.32	0.30	-
P_2O_5	0.08	0.03	-
F	0.05	-	-
CO_2	0.05	-	-
	100.07		
Less O for F	0.02		
Total	100.05	99.93	100.00

I Quartz-keratophyre of Papineau Rocks, South Australia. Anal. W.B. Dallwitz.

II Quartz-keratophyre of Marcollat, South Australia. Anal. E.R. Smith.

III "Porphyroid" of the West Coast, Tasmania. Anal. W.F. Ward.

Cambrian time and extended throughout the Cambrian period.

Volcanic rocks of Upper Pre-Cambrian age occur as acid, intermediate and basic amygdaloidal lava flows, ash and agglomerate, interbedded with Nullagine sediments in the northern half of the State. According to David (1950) they outcrop strongly in the Pilbara Goldfield and in the country at the head of the Oakover, Coongan, Nullagine, Shaw and Yule Rivers where they attain a thickness of 500 feet and in the Kimberley division. Edwards (1940) states that outcrops of basaltic rocks cover an area of about 6,250 square miles. He describes some of the basalts from the North Kimberley and concludes that there are two distinct varieties - a group of coarse grained rocks consisting of two pyroxene dolerites and a group of extremely fine grained rocks consisting of andesine basalts. The rocks are saturated with respect to silica or nearly so and resemble in their chemical composition those of Cambrian Age from East Kimberley mentioned below.

According to Prider (1945) volcanic rocks of Cambrian age are limited in occurrence to the northern part of the State where basaltic outflows cover extensive tracts in the Antrim Natural Region of North East Kimberley and extend into the Northern Territory. David (1950) estimates that they cover an area of about 9,000 square miles and have a total thickness of 2,000 feet. The volcanics are interbedded with Cambrian sediments and consist of vesicular and amygdaloidal basalts with beds of agglomerate. Edwards (Edwards and Clarke, 1940) has described varieties of basalts from the East Kimberley. They include basalts of the olivine, felspar, aphyric, quartz, pyroxene, sub-ophitic and aphanitic varieties. He states that the outstanding feature of the suite is the relative scarcity of olivine. The basalts are mostly saturated or slightly oversaturated with respect to silica and have distinct affinities with the tholeiitic basalts although they appear to be derived from a magma on the border line between undersaturation and oversaturation.

Northern Territory.

The volcanic rocks of Cambrian age in this State occur in the Victoria River and Daley River country where they are represented by basalts, andesites and dacites. This suite may possibly be Upper Cambrian. In the Edith River District similar lavas and associated pyroclastics outcrop but, according to David, Woolnough considers them to be at the base of the Cambrian and in the same relative position as the lower Antrim Plateau Basalts.

New South Wales.

In this State the Torrowangee Series, although it has been reputed to be equivalent to the upper part of the Adelaide System of Upper Pre-Cambrian age, corresponds very closely to the Dundas Group in Tasmania. This fact was mentioned by Carey and Scott (1952). According to David (1950) the series extends from about 15 miles north east of Broken Hill for over 60 miles in a north-south direction. It rests unconformably upon the Willyama schists and Mundi Mundi granite which are regarded as being Lower Pre-Cambrian in age.

Like the Dundas Group this series contains a tillite which is overlain by a volcanic suite. David states that "contemporaneous acid lavas are intercalated among the sediments in many places, and at Mt. Arrowsmith there appears to have been a centre of eruption of intermediate and basic lavas such as andesite and amygdaloidal basalt". Professor S.W. Carey who is conversant with the Tasmanian rocks of similar age and who also inspected the Heathcotian rocks in the field with the author was impressed by the similarity both lithologically and stratigraphically of the Torrowangee rocks with those just mentioned.

The glacials have been correlated by David with the Sturtian glacials of South Australia and those of King Island but this correlation was published before much work had been done on the King Island rocks. However, recent investigation seems to indicate that the King Island tillite is Middle Cambrian so if the South Australian and Torrowangee are similar they too may be Middle Cambrian. (Carey and Scott 1952).

Several specimens of the Torrowangee volcanics have been examined from various levels in the suite. They are mostly amygdaloidal and green in colour and it seems that from the specimens examined there is little variation in the basic rocks. Tuffs accompany the lavas but the specimens examined were very weathered. They have been very much epidotized.

The common rock type amongst the lavas consists of laths of plagioclase which show good multiple twinning and an extinction angle of 16^{o} indicating albite of composition $Ab_{96}An_{4}$. Sometimes tiny needles of tremolite are found in the albite. The material between the albite laths most probably has been pyroxene but it is now represented by a pale green fibrous amphibole with an extinction angle of 23^{o} which seems to indicate hornblende.

Quartz and pale green chlorite are also present between the laths. Iron ore, most probably ilmenite, judging from some sections which show skeletal habit, is abundant and granules of secondary sphene, some of which have been derived from the ilmenite are scattered throughout. Sometimes the material between the laths seems to consist almost wholly of abundant iron ore associated with tiny specks of sphene. In fact the rock seems as if it has been sprinkled with iron ore. Under high power some quartz and needles of tremolite are seen to exist also between the laths. The rocks are usually amygdaloidal, the amygdules being irregularly shaped and ranging up to $\frac{1}{8}$ inch in diameter. Sometimes epidote, showing good cleavage and often twinning, either simple or multiple, is the only mineral constituent of the vesicles while combinations such as (a) lined with iron ore and filled with granular albite with twinning, quartz, epidote, amphibole, and iron ore, (b) lined with albite and filled with epidote, (c) lined with iron ore and filled with albite, or albite, calcite, and epidote exist.

These Torrowangee rocks described above are not unlike the "mugearites" described by Nye, Finucane and Blake (1934) from Smithton.

In parts the lava has been converted to an epidote rock which consists of a mass of granular yellowish green epidote, pale green chlorite and amphibole with irregularly shaped grains of sphene and some iron ore. Occasionally patches of quartz with tiny needles of almost colourless tremolite exist.

Queensland.

The Brisbane Metamorphics of this State which are the equivalent of the Brisbane Schists of older workers include the Rocksberg Greenstones. Bryan and Jones (1951) provisionally place the Greenstones in the Cambrian but state that they may well be older. No fossils have been found.

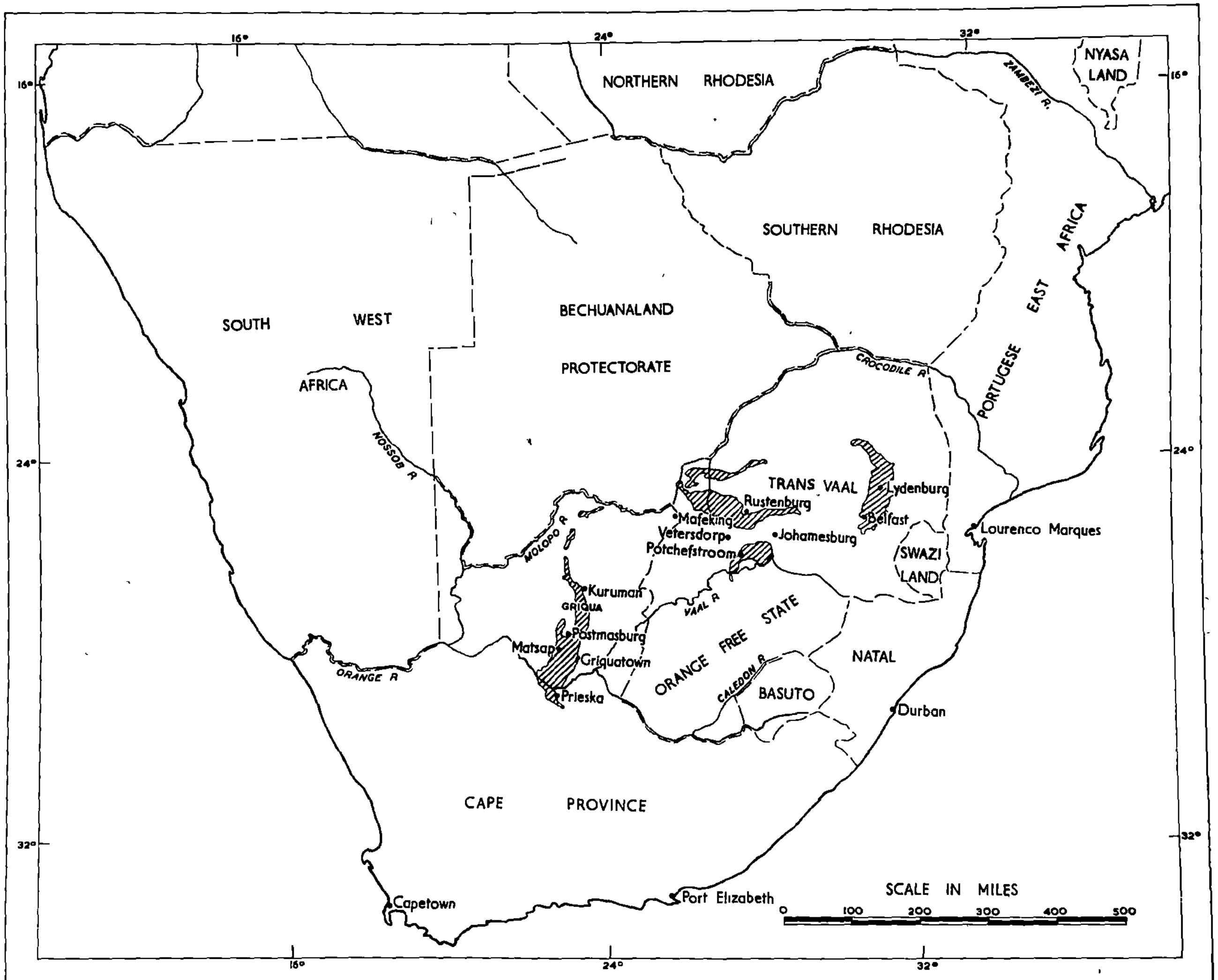
The Greenstones are restricted to a belt extending about 20 miles north of the North Pine River. They consist of metamorphosed basic rocks which were possibly originally basalts, andesites, and pyroclastic rocks. Generally the rocks are massive but in places they are highly schistose and consist usually of albite, actinolite, epidote, sphene and minor chlorite. Some varieties are porphyritic in altered felspar and in others large relict euhedral augite phenocrysts are common. They are probably altered basic to intermediate lavas.

Unfortunately, the author has not had the opportunity to examine specimens of these rocks. However, in a discussion with Dr. D. Thomas, Chief Government Geologist in Victoria, who is conversant with the Heathcotian rocks in Victoria, and the Dundas rocks in Tasmania, he expressed the opinion that the Greenstones are very similar to the Heathcotian and Dundas rocks and when an intensive search for fossils is made he considers that results will indicate an age older than is at present given.

South Africa.

In the Transvaal in South Africa, the Transvaal System bears a similarity in its stratigraphy to that of the late Pre-Cambrian and Cambrian in Tasmania. The following brief outline of the stratigraphy is after Du Toit (1939) and Truter (1949).

This system occupies the greater part of the Central Transvaal and everywhere rests evenly and unconformably on older rocks. Its lowest member is the Black Reef Series, a series of dense, hard dark quartzites, followed by the dolomite which could possibly be the counterpart of the Smithton Dolomite. This dolomite has a maximum thickness of 7,000 feet but is known to vary to much smaller thicknesses within short distances.



DISTRIBUTION OF PRETORIA AND GRIQUATOWN SERIES IN SOUTH AFRICA (after Du Toit)

Figure 10

It is composed almost entirely of well-bedded magnesian limestones with subordinate bands of chert. Sometimes oolitic structures are present. The rock is blue-grey, compact or minutely crystalline but pink, red and purple varieties are known. Overlying the dolomite is the Pretoria Series with a thickness of 7,000-10,000 feet exclusive of the igneous intrusions. This series consists of three stages, the basal member being the Timeball Hill Stage, followed by the Daspoort and Magaliesberg Stages respectively. The Timeball Hill Stage is composed of shales and quartzites for the most part, but to the author the Daspoort Stage is the most interesting because it is in it that the Ongeluk lavas appear about two thirds up in the sequence. Underlying the lavas in places is a glacial band which attains a maximum thickness of over 200 feet. It is sometimes both under and overlain by ordinary shales and then by the volcanics. This glacial band has the character of a tillite and appears as though it may be the equivalent of the tillite which persistently underlies the volcanics on King Island and in Tasmania. The Ongeluk lavas have a thickness of about 1,500 feet in the southern part of the country but range up to 5,000 feet in the Zeerust district. The lavas are mostly fine grained, greenish blue coloured andesitic rocks varying from compact stony types to highly amygdaloidal varieties. Breccias and tuffs accompany the lavas. Included in the Magaliesberg Stage are more tuffs and lavas, i.e. the Machadodorp pyroclasts and the Dullstroom andesites, which seem to resemble the Ongeluk type and the Rooiberg felsites and pyroclasts.

In the Northern Cape the Transvaal System is represented by the Black Reef Series, Campbell Rand Series which is the equivalent of the dolomite and the Griquatown Series which is the equivalent of the Pretoria Series. The Griquatown Series consists of two groups of banded ferruginous jasper beds which are separated by the Ongeluk Volcanic Series. Immediately below the volcanic group or separated from it by a small thickness of strata is the Griquatown Tillite consisting of unsorted pebbles and boulders of all sizes and shapes, some of which are striated. The tillite is less than 100 feet thick and passes downwards into bedded strata. This glacial bed is the representative in this district of the glacial horizon in the Daspoort Stage of the Pretoria Series. It has been estimated that the Ongeluk lavas are over 1,000 feet in thickness. They are similar in appearance to those in the Pretoria Series. "Under the microscope are to be seen feathery microlites of augite or hornblende, small felspars and crystals of enstatite (or bastite pseudomorphs after that mineral) set in a devitrified base". Chalcedony calcite and chlorite fill the vesicles. Volcanic breccias, tuffs and related intrusives are present. "Along the Mashowing and Kuruman Rivers some of the lava flows exhibit "pillow-like" structures, large blocks of compact rock up to 8 feet across rounded at edges and corners being separated from one another by darker laminated decomposed substances in which masses of vein-quartz fill up wedge-shaped spaces." Peculiar to this group are jaspers and cherts in the form of very thin layers in the lavas.

The above outline of the stratigraphy and correlation is summarized in the following Table XII.

<u>Ongeluk Lavas</u>.

Appearing in the Annual Reports of the Cape Geological Commission are many descriptions of both hand specimens and thin sections of the Ongeluk lavas. These are summarized briefly below.

The lavas are chiefly compact fine grained, blue-green rocks which show little or no structure in the hand specimens. Black specks, rarely 1 mm. in length, are visible. "Under the microscope the black spots

TABLE XII - SUGGESTED CORRELATION OF SOUTH AFRICAN AND TASMANIAN CAMBRIAN ROCKS.

SOUTH AFRICA			TASMANIA		AGE
Transvaal System	Pretoria Series	Magaliesberg Stage (incl. Rooiberg felsites, Dullstroom andesites and Machadodorp pyroclastics) Daspoort Stage (incl. Ongeluk andesites and tillite) Timeball Hill Stage (Shales and quartzites)	Dundas Group	Slates, cherts, greywackes, tillite, lavas, pyroclastics	Middle Cambrian probably also including some Lower Cambrian
Transvaal System	Dolomite Series	Dolomite	Carbine Group	Dolomite (cf. Smithton)	Lower Cambrian or Late Pre-Cambrian
Transvaal System	Black Reef Series	Quartzites	Carbine Group	Quartzite (cf. Bryant Hill)	Lower Cambrian or Late Pre-Cambrian

are seen to be enstatite crystals or pseudomorphs after that mineral and the groundmass is made of feathery aggregates of a fibrous mineral, very pale green, non pleochroic, and usually with an extinction angle of several degrees off the length of the fibres." The interference colours are yellowish white and the mineral resembles an amphibole. "No felspar laths nor any indication of them are visible. In amongst the feathery hornblende is some quartz in the form of a minute mosaic. Small grains of epidote are present." The rock was regarded as a variety of enstatite andesite. Another type of lava, less compact than the above appears under the microscope to consist of a greatly altered groundmass in which there are small porphyritic crystals of two kinds, one being augite in long and irregularly bounded prisms and the other, which now occurs as pseudomorphs of serpentinous material is in shorter prisms with straighter boundaries. The shape of the latter indicates enstatite. Some felspar still remains but is partly decomposed. The bulk of the groundmass is made up of very minute areas of more or less clear minerals and appears to be isotropic under low power but under $\frac{1}{8}$ inch objective splits up into smaller areas. This rock, a common type in the Ongeluk Series was given the name of a pyroxene andesite.

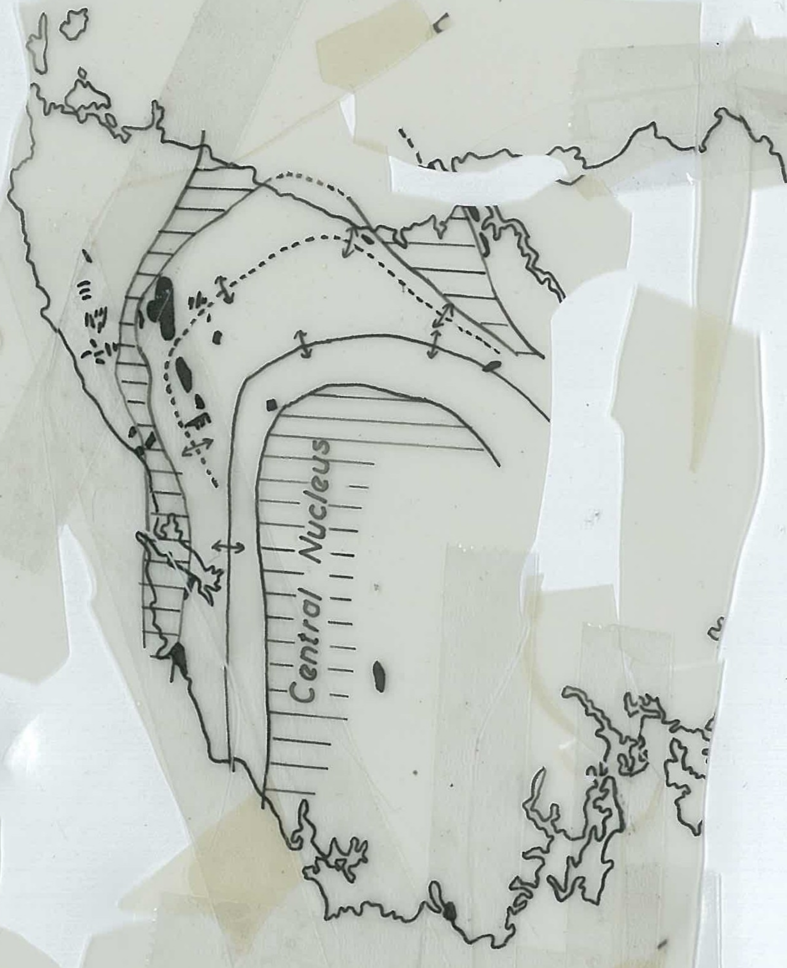


FIGURE 12

Basic and ultrabasic intrusive r

West Coast Range Geanticline

Bischoff Anticlinorium (M. Dev.)

As mentioned above tuffs and breccias accompany the lavas. Under the microscope the breccia seems to consist of fragments of vesicular lava set in a matrix which contains epidote and much quartz. One lava fragment is made up chiefly of small felspar laths belonging to the oligoclase-andesine group, set in an indeterminate base. This lava differs from the others in that it contains no visible ferromagnesian mineral. An altered fine grained tuff has been described as containing "very fine grained material in which quartz, in the form of a mosaic, is the most important constituent but with the quartz there are a great number of very minute, more highly refracting yellowish grains and short needles."

Intrusive rocks such as diabase are associated with the Ongeluk volcanic series. An examination of the diabase under the microscope would indicate that it consists of colourless augite in elongated sections. The felspar is altered to aggregates of other minerals, including epidote, chlorite, quartz and colourless hornblende. Patches of felspar may be left among these aggregates but they do not show twinning. No calcite is amongst the alteration products. A considerable amount of original quartz is present and some is intergrown with what was once felspar. Leucoxene and iron ores are present in small amount. The original nature of the groundmass of the rock is obliterated. It was probably not holocrystalline.

In the 1906 report an interesting statement is made when the banded jaspers which are associated with the lavas are being described. "The mineral taken to be garnet is in spherical aggregates without crystal faces, it is nearly colourless, and has a higher refractive index than epidote and it is isotropic." This description could well fit the hydrogrossular which occurs in the King Island rocks. In any case, it is interesting to note that Hall (1924) described a massive garnet, "jade", from the Bushveld in Western Transvaal and in light of recent research this garnet has proved to be hydrogrossular.

The author has had the opportunity to examine thin sections of the Ongeluk lavas from the Potchefstroom and Rustenberg Districts. Brief descriptions of these are as follows. The number of the section and the localities are presented as given by Professor F. Walker when he sent the slides.

<u>5.101 Bankdrift 549, S 25° 48' E 26° 48', Rustenberg District.</u>
This rock consists of irregularly arranged felspar laths about 0.75 mm. in length which have been completely replaced by sericite. The ferromagnesian mineral is pale

green fibrous hornblende which is very slightly pleochroic and has an extinction angle of $17\frac{1}{2}^{o}$ but when full plates of the mineral are developed the extinction angle varies up to 31^{o}. The hornblende is definitely secondary and probably replaces pyroxene, the cleavage of which is still retained. Evidence of the secondary nature of the hornblende is seen when some of the fibres pierce the vesicles of recrystallised quartz. Patches of calcite are present and it may be possible that some of these are the replacement products of pyroxene. Now and again patches of granular clinozoisite occur between the laths of sericitized plagioclase and hornblende, that is, in the position in which chlorite is usually found in such rocks. The rock is quite vesicular and the vesicles, which are up to 3 mm. in size and irregularly shaped, have mostly been recrystallized. They are lined with sericite (which was probably originally albite as small pieces of unaltered albite still remain) with quartz usually as large grains varying almost to idiomorphic crystals, occupying the centre. Sometimes a few idiomorphic to subidiomorphic crystals, 0.5 mm. in size, of clinozoisite accompany the quartz. The clinozoisite shows anomalous blue interference colours and basal parting. At other times needles of the tremolite accompany the quartz.

Other vesicles are filled with calcite and still others with either albite or quartz surrounded by finely granular clinozoisite associated with a little calcite. An interesting feature is that around some of the vesicles the rock is more finely grained and the felspar has been altered to hornblende and chlorite. Very little chlorite is present in the rock.

<u>61.603 Kolomesplaas, S 26° 37', E 27° 7', Potchefstroom.</u>

Tiny laths of plagioclase, 0.1 mm. to 0.5 mm. in length are separated by irregularly shaped areas of chlorite which are probably replacing pyroxene. Some of the patches are fringed with granules of sphene. The plagioclase has been replaced by albite, chlorite and clinozoisite which seems to be quite prevalent. In ordinary light the laths of plagioclase are quite distinctive but under crossed nicols the whole mass appears to be altered to clinozoisite. Some of the patches of this mineral which approach a large uniform grain in shape show the development of twinning and good cleavage. It shows first order yellow interference colours and straight to slightly oblique extinction. Irregularly shaped vesicles, 2 to 3 mm. in size are filled with a mosaic of quartz and clinozoisite. At times, these minerals have the appearance of an intergrowth which lines the vesicles. Other vesicles are either filled with radiating quartz and are lined with fine grained quartz or the intergrowth, or else lined with a double row of clinozoisite and filled with chlorite and albite. In one vesicle a bright grass green coloured chlorite is found.

<u>61.604 Klerksdorp Road, S 26° 45.1', E. 27° 1.2', Potchefstroom.</u> This rock is almost doleritic in grain-size. The laths of plagioclase are 1 mm. in length and have been partly altered to chlorite. Multiple twinning is common. The pyroxene still shows a certain amount of crystal outline but has been altered to a pale green chlorite with anomalous interference colours in the centres while the edges have taken on a brown colour and are often dotted with granules of sphene. In spite of the brown colour the edges still retain the double refraction of the pyroxene. The extinction angle is 40° and the double refraction 0.023. A large vesicle showing a weird pattern of very fine granular quartz and chlorite is present. Patches of quartz and patches of a mosaic of tiny quartz granules and chlorite are present. Some of these patches contain a large amount of sericite and others albite.

61.605 Potchefstroom townlands, S 26° 45.4', E 26°, 59.3' Potchefstroom. The rock is fine grained and contains subidiomorphic crystals of fresh pyroxene which show simple and multiple twinning. The pyroxene seems to be very pale green to fawn in colour and has a double refraction of 0.018. In parts it shows a tendency to ophitic fabric. Beside the pyroxene there is a groundmass of felspar laths which show multiple twinning and granules of quartz and chlorite. The plagioclase has a maximum extinction angle of 31° indicating that it is labradorite with the composition Ab_{45} An_{55}. A little ilmenite altering to leucoxene is present and also a few patches of calcite. The vesicles contain quartz and chlorite.

61.608 Vyfhock 131, North of Tarentaal, S26° 40', E27° 11'. This rock has an amazing appearance under the microscope. It consists of radiating sheaves of clinozoisite (see figure 1, plate VII). The material between the branches of the sheaves is almost irresolvable but is most likely a mixture of quartz and felspar as a few specks of sericite are evident. Idiomorphic to subidiomorphic phenocrysts of pyroxene are present but some of them have been completely pseudomorphed by chlorite while others have a border of clinozoisite. Sometimes the radiating material cuts across the border of the clinozoisite. Where this has happened the outlines of the individual crystals can be seen but both minerals are similarly orientated optically. The crystals in the sheaves are very narrow with cross parting, oblique extinction and first order yellow interference colours.

<u>53.801. Buffelsdorp 143, S26° 29', E27° 22' Potchefstroom.</u>
The rock is greatly silicified with only skeleton like crystals which were once pyroxene in a brown devitrified glassy base. The crystal outline and cleavage are represented by narrow borders of clinozoisite. The rest has been replaced by finely crystalline quartz, chlorite of the pennine variety or clinozoisite. The latter mineral is colourless to very pale green, shows straight and oblique extinction up to 40°,(unusually high) low first order interference colours and one fair cleavage and is length fast. The phenocrysts are up to 3 mm. in length and have varying shapes as illustrated in figure 2, plate VII. Some are long with pointed ends and have basal parting. These may have possibly been felspars except that the presence of the parting is extraordinary if such is the case. Others are almost rectangular or prismatic with pyramidal caps. These were probably pyroxene. The base of the rock was no

doubt originally glassy but now shows incipient crystallization. The rock is vesicular and the vesicles are filled with either granular quartz with albite towards the centre or with a mass of tiny spherules of quartz with some chlorite. Each spherule shows a cross of polarisation.

<u>53.802. Elandofontein 122, S 26° 28', E 27° 25', Potchefstroom.</u> Laths of plagioclase in the rock have been replaced by clear albite without twinning, chlorite and sericite, while the pyroxene which was apparently present in plates up to 1 mm. in size has been mostly replaced by pale green chlorite. A little unaltered pyroxene remains. It has an extinction angle of 43° and a double refraction of 0.023. Granules of sphene are scattered throughout the rock and a few small patches of quartz are present.

<u>53.803. Elandofontein 122, S 26° 28', E 27° 25', Potchefstroom.</u> The pseudomorphs of clinozoisite after pyroxene in this rock average 0.5 mm. in size, have first order pale yellow interference colours, an extinction angle of 43° and show simple and multiple twinning. Alteration to pale green chlorite seems to have begun always at the centre while the clinozoisite occupies the outer part of the crystal giving it a

skeletal appearance under crossed nicols because of the difference in double refraction of the two minerals. The chlorite is of the pennine variety. Patches of quartz are present and seem to wrap round some of the laths of plagioclase which is altering in part to chlorite. The unaltered plagioclase shows multiple twinning and has a maximum extinction angle of 30^{o} indicating the labradorite variety with a composition Ab_{47} An_{53}.

The South African lavas have been more greatly altered than those in Tasmania but it is interesting to note the presence of a basic plagioclase in spite of abundant albitization. Petrographical evidence, revealed in the descriptions of the lavas from the literature and gained from personal observation, suggests that the original unmetamorphosed rocks may have been similar to those in Tasmania. The author is inclined to think that the South African andesites, so-called, were originally more basic. They were most likely basalts of several varieties.

Rooiberg Felsites.

The Rooiberg felsites are extremely interesting and seem to warrant special mention. Evidence from the available literature seems to indicate that they have been a puzzle to the South African geologists just as the porphyroids, porphyries, keratophyres and felsites have been to the Tasmanian geologists. The eruptions of acid lavas are thought to be related to the emplacement of the Bushveld granite, of which the lavas are regarded to be the earlier extrusive equivalents. The lavas and granite correspond in areal distribution. As in Tasmania the term "felsite" is apparently a "sack" into which have been placed both effusive rocks of different composition and pyroclastic rocks. According to Truter (1949) the effusives consist mainly of reddish coloured very fine grained rocks of rhyolitic character and composition as well as quartz and felspar porphyries and more basic types such as andesites. Pseudospherulitic and flow structures are reported to be common features of these acid lavas while the more basic varieties are amygdaloidal. The fragmental rocks range from coarse agglomerate to tuff and ash.

The felsites are usually stony looking and do not contain conspicuous minerals. Sometimes they carry small phenocrysts of pink felspar, usually albite, but with scanty ferro-magnesian minerals, chiefly hornblende.

Hall (1932) gives comprehensive descriptions of the various types of felsite. It is not proposed to deal with them here but in a description of the normal non-amygdaloidal felsites he says that microscopic examination shows abundant felspar, quartz, a little augite and hornblende, with magnetite and apatite as rare accessories. The presence of augite is interesting in view of Tasmanian and South Australian equivalents. Also, in the description of the nodular and spherulitic felsites he mentions that augite is frequently met. The groundmass of the lavas is often granophyric. The description of the soda trachyandesite is very reminiscent of those of the Montana melaphyre and trachybasalts described from Tasmania.

Petrographic evidence indicates that these felsites may be the equivalents of the porphyroids etc. in Tasmania.

Associated with the Pretoria Series as with the Dundas Group in Tasmania are acid rocks (granites and albite syenites), basic rocks (norites) and ultrabasic rocks (peridotites and pyroxenites, both serpentized). In South Africa these igneous rocks belong to the Bushveld Complex which is intrusive into the Pretoria Series.

It seems that the general petrological picture of the Pretoria Series in South Africa is very similar to that of the Dundas Group in Tasmania, which supports the correlation of these groups long maintained by Professor Carey on more general stratigraphic grounds.

BASIC AND ULTRABASIC INTRUSIONS ASSOCIATED WITH THE LAVAS.

Figure 12 illustrates the distribution of the basic and ultrabasic rocks in Tasmania. It seems more than coincident that these rocks are so closely associated in the field with the volcanic rocks. In fact, it is commonly known that ultrabasic and basic intrusions are associated geographically with spilitic rocks. According to Reid (1921) the largest outcrops of these rocks occur at Heazlewood, Long Plain, Wilson River, Renison Bell, Dundas, Spero River, Hamilton Range, Boyes' River, Florentine River, Styx River, Birch's Inlet and the Salisbury District.

Not only do they correspond closely in distribution but also in time. Certainly they are post volcanism but Professor Carey (personal communication) has dated them as Upper Cambrian. At Adamsfield he has found a conglomerate composed of pebbles of serpentine set in a serpentine matrix, i.e., the conglomerate was formed from material shed directly from the serpentine. This serpentine conglomerate immediately underlies slates containing Tremadocian fossils. The slates in turn underlie the West Coast Range Conglomerate of lower Ordovician age. This discovery by Professor Carey has definitely

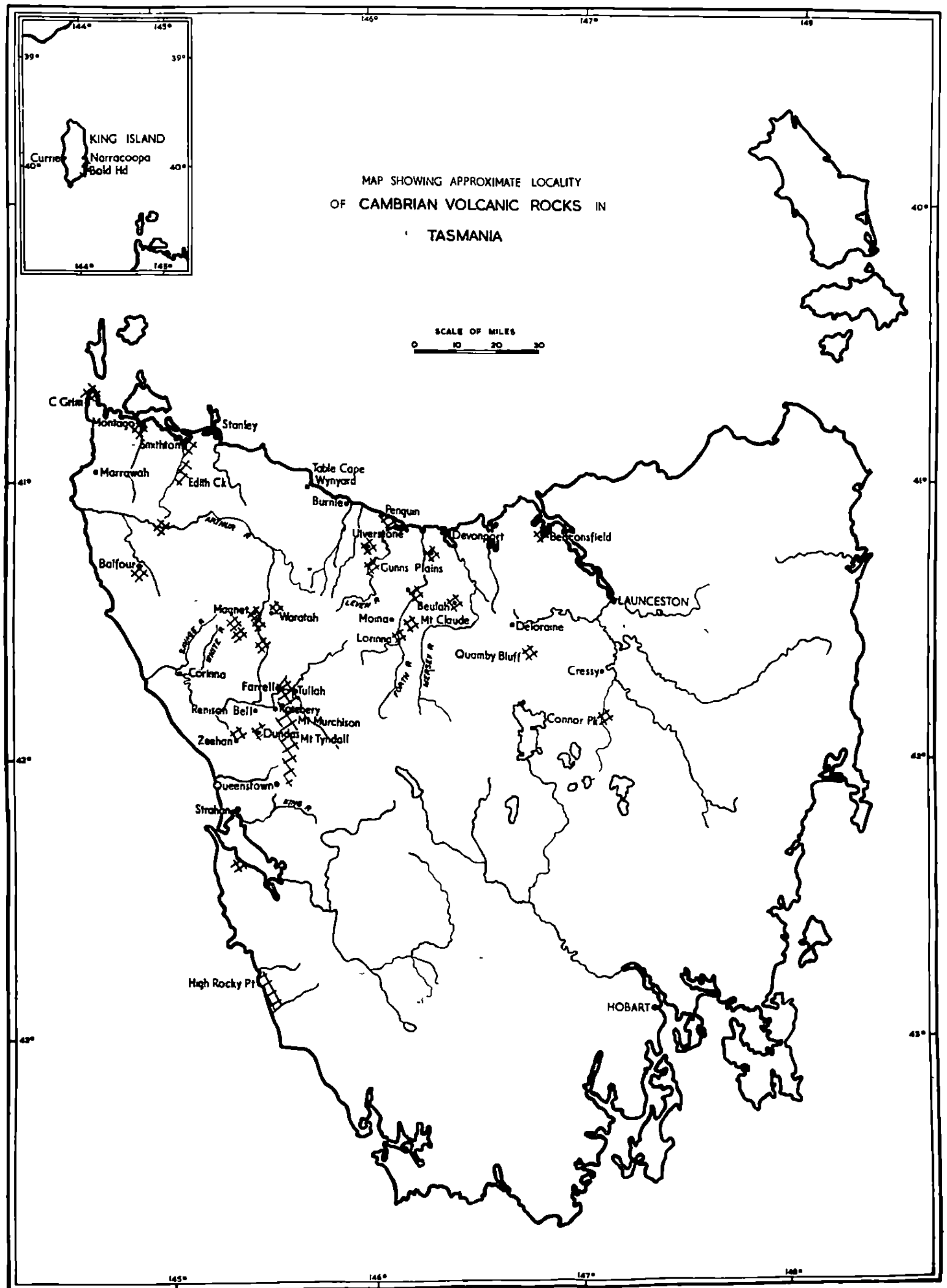

MAP SHOWING APPROXIMATE LOCALITY
OF CAMBRIAN VOLCANIC ROCKS IN
TASMANIA
SCALE OF MILES
0 10 20 30
KING ISLAND
Currie
Narracoopa
Bold Hd
C Grim
Montagu
Smithton
Stanley
Marrawah
Edith Ck
Table Cape
Wynyard
Burnie
Penguin
Ulverstone
Devonport
Beaconsfield
Balfour
Gunns Plains
Magnet
Waratah
Beulah
Moina
Mt Claude
Lorinna
LAUNCESTON
Deloraine
Quamby Bluff
Cressy
Corinna
Farrell
Tullah
Renison Bell
Rosebery
Mt Murchison
Zeehan
Dundas
Mt Tyndall
Connor Pk
Queenstown
Strahan
High Rocky Pt
HOBART
144°
145°
146°
147°
148°
39°
40°
41°
42°
43°

Figure 1

dated the serpentines in Tasmania which were originally regarded as being Devonian.

The study of these rocks is outside the scope of the present thesis. They are mentioned mainly because of their place in the general picture. No recent petrological work has been done on these rocks, so use has to be made of existing information, the reliability of which is doubtful.

The ultramafic rocks are present in the form of sills and, according to Reid (1921), are represented by a peridotite group which includes dunite, harzburgite, lherzolite and wehrlite and a pyroxenite group including diallagite, websterite, bronzitite and websterite porphyrite. The mafic rocks are represented by gabbro and norite for the most part and appear to be olivine free. The ultramafics have been greatly serpentinized and at times carbonated and silicified, while the gabbroic rocks likewise have been altered, the labradorite to saussurite and the pyroxene to uralite.

It is worth noting that some of the rocks mapped and described by earlier workers as pyroxenites and serpentinized pyroxenites are really dolerites and gabbros which have been quite altered, as revealed by observation under the microscope.

The author believes that these basic and ultrabasic rocks are genetically related to the lavas. Bowen and Tuttle (1949) have shown by laboratory work that a molten ultrabasic magma cannot exist. They point out that the ultrabasic material could have been derived by crystal sinking during differentiation as above, or derived from the peridotite layer in the depths of the earth, but in either case it must be intruded in the solid. Hess (1939), although postulating a primary peridotite magma as being the product of partial fusion of the peridotite substratum and of composition roughly the same as that of serpentine, devised criteria for distinguishing between the ultramafic rocks of the ultramafic magma series and those of the basaltic. He states that the most important difference in composition between ultramafics of the different magma series is their Mg/Fe molecular ratio and that all of the Mg/Fe ratios of peridotites, dunites and serpentinites of the ultramafic magma series are above 7.5. The pyroxenites related to this series generally have ratios between 3.5 and 7.5. The ultramafics derived from a mafic magma have ratios between

3.5 and 7.5 and the pyroxenites, ratios averaging 4.1. As well as the Mg/Fe ratio, the rocks belonging to the primary ultramafic magma series are commonly lower in CaO and Al_2O_3 than those of the mafic series because the latter tend to contain a little plagioclase and as well diopsidic pyroxene of an aluminous variety.

These tests were applied to the ultramafics in Tasmania, using all the chemical analyses available. All fell below the requirements necessary for the rocks to have been derived from the peridotite layer. The results are tabulated in Table X. (p.102)

If the analyses are correct then they appear to be somewhat abnormal. The alumina content is abnormally high. Reid (1921) states "The high proportion of alumina is due in a measure to concentration by the dissolution of the soluble component, and in part to the presence of much bronzite. ----The high alumina content of the bronzite is extraordinary and seems peculiar to the osmiridium bearing rocks." and later "The high percentage of alumina is probably due to concentration during serpentinization and the solution of certain original components." It is to be wondered if Reid understood what he wrote for his statements were certainly not elucidated by explanations of these "soluble components". If the analysis of the bronzitite, which should be an almost monomineralic rock, is examined, it is found to contain only 3.5% Al_2O_3, so it is hardly correct to blame the bronzite for the presence of high alumina.

After reading the petrographical descriptions of the rocks as given by Reid, the author is at a loss to see where the alumina could fit. The peridotites are supposed to be completely serpentinized. One suggestion is that the serpentine has been misidentified and is actually an alumina rich chlorite. It was pointed out earlier that some of the rocks mapped and described as pyroxenites are not pyroxenites but dolerites. It is possible that some of these so-called serpentines are really partially altered dolerites and gabbros, in which case, a higher content of Al_2O_3 would be expected.

THE RELATIONSHIP OF BASIC VULCANISM, BASIC AND ULTRABASIC INTRUSIONS AND METASOMATISM TO GEOSYNCLINAL DEPOSITION AND OROGENY.

The group of sediments with which the volcanic rocks are associated is typical of eugeosynclinal deposition. The sediments were deposited in the Dundas geosyncline which is peripheral to the Central Tasmanian Nucleus or Craton, a belt of Pre-Cambrian rocks about 25 miles wide which stretches northwards from Port Davey to Cradle Mountain (Carey, 1950). This geosyncline contains about 11,000 feet of Cambrian cherts, slates, conglomerates, volcanics and greywackes, the latter being derived, for the most part, by rapid erosion and deposition from the basic volcanic rocks. In addition to the Cambrian there are, in the geosyncline, several thousand feet of underlying Carbine Group and nearly ten thousand feet of Ordovician, Silurian and Lower Devonian strata.

According to Turner and Verhoogen (1951) the variation in the type of igneous activity and the nature of the corresponding rock associations in a single major orogenic cycle tends to conform to a single broad pattern, as follows:

1. Eruption of dominantly basic (including spilitic) lavas, during the geosynclinal

phase of the tectonic cycle.

2. Injection of ultrabasic and basic plutonic intrusions during the early stages of folding. In some cases this overlaps with phase 1.

3. Development of granodioritic and granitic batholiths during and following the main period of folding.

4. Surface eruption of basalts, andesites and rhyolites during and following elevation of the folded mass. This phase is typically separated by a lengthy period of time from the main phase of folding and plutonic activity.

However, it is with the first three phases that the author is more concerned.

Phase 1 indicates that geosynclines (eugeosynclines) are sites of vulcanism during the stages of sedimentation and suggests that rising temperatures must have existed at the base of the geosyncline. The writer believes that the lavas were not spilitic when ejected but were normal basaltic lavas intermediate in composition between a tholeiite and an olivine basalt (see section on Chemical Composition, etc.).

As mentioned in the last section, the spilitic rocks are associated with basic and ultrabasic intrusives which were intruded at a later period than the extrusion of the volcanic rocks. These intrusions, then, fit into the time scale outlined above.

Phase 3 is also represented on the West Coast of Tasmania. Small bosses of granite, syenite, etc. and their hypabyssal equivalents have been developed probably late in the Cambrian. Both intrusive and metasomatic origins have been put forward for these granites. Earlier workers suggested they were intrusive but recently Mr. J. Bradley (formerly of University of Tasmania) put forward the idea that they are the result of the granitization of preexisting sediments in situ. Because the author has not studied these rocks in detail she wishes to keep an open mind on the subject, but she admits that there is strong evidence to support the idea of a metasomatic origin. Such an origin would fit well into the scheme suggested by Misch which seems to hold for these West Coast rocks. The time of the metasomatic alteration of the lavas and sediments is consistent with that of the development of granites in phase 3.

Misch (1949) states that metasomatism is genetically linked with orogeny. The author is in complete agreement with Misch on this point because as far as the Tasmanian rocks are concerned metasomatism was post vulcanism and basic and ultrabasic intrusion since both sets of rocks resulting from these phenomena have been affected.

The Tyennan uplift which commenced in the early Middle Cambrian and continued throughout the Upper Cambrian was coeval with the Dundas sedimentation according to Carey (1952). It was probably during this orogeny, particularly in its latest stages when the accumulation of sediments was greatest that metasomatism took place. The metasomatic alteration resulted in widespread albitization and silicification accompanied by other changes such as chloritization and epidotization which required additional Al_2O_3, no doubt provided from pelitic sediments. This metasomatic alteration was responsible for the formation of the so-called spilitic rocks and porphyroids, altering the gabbros and possibly causing the serpentinization of the ultrabasic rocks.

The alteration was differential because the rocks are altered to various degrees. In places it has been so advanced as to give rise to the formation of granites (e.g. Darwin granite) and syenite such as in the

Murchison Gorge south of Mt. Farrell. The greatest development of the "porphyroid" group is approximately along the crest of the West Coast Range anticlinorium which was rising during the last phases of the orogeny.

If a very general picture of the structure is considered, there appears to be a kind of zonal arrangement in the metasomatism of the lavas. These zones are as follows:

1. A zone along the geanticline where soda metasomatism was predominant together with silicification resulting in the formation of the porphyries and keratophyres.
2. West of the zone, through Zeehan, Magnet and Leven Gorge is a zone where silica metasomatism predominated.
3. Further west still, through High Rocky Point, Smithton and King Island is a zone of very little alteration apart from albitization.

Evidence that this phase of metasomatism was completed before the deposition of the basal beds of the Junee Group (Lower Ordovician) is revealed by the presence of boulders of Darwin granite (reported by Hills, 1914) and "porphyroid" (verbal communication by Banks) in the West Coast Range conglomerate.

However, there was another more violent period of orogeny, the Tabberabberan of Middle Devonian age, which was also accompanied by a period of hydrothermal alteration. This period of alteration was responsible for the widespread silicification of the West Coast Range conglomerate.

During the Tabberabberan orogeny an important very deep shear, which in places has its surface expression in a fracture and elsewhere as a zone of overturned attenuated strata was developed according to Carey (1952) who expresses its distribution thus "What is suspected to be the continuation of this structure runs from the southern end of Mt. Darwin through the Jukes copper prospects, then northwards to Mt. Lyell, through the Comstock workings, then through the eastern end of Lake Margaret whence it may extend northwards to the Red Hills copper prospects continuing thence into the shear zone of the Sterling Valley mine, then across the Murchison through the Mt. Farrell field." This overturned and attenuated zone is associated with local sericitization and with numerous hydrothermal ore bodies.

The so-called hornblende andesite from the Tyndall Range near Lake Margaret is very close to this shear zone. It is possible that the development of the hornblende which, as indicated in a previous section, probably needs a slightly higher temperature of formation and followed the low temperature alteration may belong to this second period of metasomatism. Most probably the earlier formed porphyroids suffered further alteration and shearing. Two periods of alteration are suggested by petrographic evidence and it is interesting to note that the second period gave rise to the development of more quartz than albite.

Carey (1952) is inclined to believe that the silicification of the lavas in the Zeehan - Magnet District took place during the Tabberabberan orogeny. Certainly it, and the silicification of the lavas to jaspers near Penguin (found since Carey's publication), fit into his structural pattern but apart from this the author has no definite evidence to indicate to which orogeny it belongs. Since silicification is a common phenomenon associated with spilites elsewhere in the world she is inclined to think that it may belong to the Tyennan orogeny, thus completing the "spilitization" in the one period.

SUMMARY AND CONCLUSIONS.

An attempt has been made to elucidate the nature of the Cambrian volcanic rocks of Tasmania.

Several occurrences of basic rocks which were regarded as dykes have been proved to be volcanic rather than hypabyssal. The "dyke" at Smithton has been proved conclusively to be part of the volcanic suite and there is strong evidence to support a suggestion that the Magnet "dyke" is likewise volcanic. The dolerite of Lower Palaeozoic age near Penguin is also volcanic.

The Cambrian volcanic rocks of Tasmania which outcrop predominantly over a wide area on the West Coast and along the south east coast of King Island form an interesting petrographic province. Unfortunately a host of vital detail with regard to differentiate products has been masked by alteration. The nature of the volcanics and their subsequent alteration has been controlled by the eugeosynclinal environment.

The most important points to be drawn from the study are as follows:

1. The volcanics comprise a spilitic suite consisting of picrite basalts, spilites, keratophyres, albite dolerites, and associated pyro-

clastics which were erupted into the Dundas eugeosyncline during the Middle Cambrian.

2. The magma, when erupted, was not soda rich but of a composition intermediate between that of a tholeiite and that of an olivine basalt, having tholeiitic affinities in its high SiO_2 and low MgO contents and olivine basaltic affinities in its undersaturation (as revealed by the norms), the presence of diopsidic augite and its differentiate products.

3. Chemical analyses indicate that the lavas are rich in alumina and low in titania. Evidence has been produced to indicate that the alumina did not belong to the magma originally but was gained later, probably from aluminous pelitic sediments during the period of metasomatism.

4. The associated basic and ultrabasic intrusions are related to the volcanics but were intruded at a later date. (Upper Cambrian.)

5. The Tasmanian volcanics are most likely the eugeosynclinal equivalents of the volcanics of similar age in South Australia where they are miogeosynclinal and Western Australia where they

were erupted on to the stable shield.

6. The association of greywackes, porphyries and keratophyres, developed from sedimentary and volcanic rocks, containing albite points to a secondary origin for the albite, although the study on King Island indicated a possible primary origin because of ophitic relation and intergrowth between diopsidic augite and albite.

7. Hydrothermal alteration is prevalent and the main types are albitization, silicification and chloritization thus indicating an enrichment in Na_2O, SiO_2 and some Al_2O_3. The mineral assemblage developed indicates low temperature conditions although the formation of Hydrogrossular and possibly hornblende indicate local rises in temperature.

8. Silicificationis revealed by the abundance of secondary quartz in the lavas, and the formation of jasper and spherulitic quartz rock.

9. Soda and silica metasomatism of the lavas along a major geanticlinal structure has given rise to the formation of a variety of porphyries and possibly keratophyres.

10. The chemically active solutions which caused the hydrothermal alteration were activated by heat and movement during the Tyennan orogeny

(Late Cambrian) giving rise to metasomatism which affected the lavas. The Tabberabberan orogeny (Middle Cambrian) was responsible for further alteration of the "porphyroids" and possibly the development of the hydrogrossular on King Island and hornblende on the Tyndall Range.

11. The origin of the soda and silica remains a moot point. Claims have been made to an origin below the geosynclinal prism (Misch) or redistribution of those constituents within the sediments of a geosyncline. Additional Na^+ could have been obtained from sea water entrapped in the pore spaces of the sediments.

12. The lavas occur in a variety of forms - massive, pahoehoe and aa flows and in pillows. The presence of aa lavas and columnar jointing in the King Island lavas indicates subaërial conditions in that locality. The lavas were extruded for the most part quietly from fissures into the sea but the presence of pyroclastics indicates periods of explosive vulcanicity.

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LOCALITY INDEX.

Locality	Quadrangle	Latitude S.	Longitude E.
Adamsfield	Huntley 73	42° 49'	146° 20'
Arthur River	Magnet 35	41° 28'	145° 27'
Bankdrift	(South Africa)	25° 48'	26° 48'
Balfour	Balfour 34	41° 16'	144° 55'
Beaconsfield	Beaconsfield 30	41° 11'	146° 45'
Beulah	Sheffield 37	41° 26'	146° 24'
Birch's Inlet	(Macquarie Hbr. 64 (Pillinger 65	42° 27'	145° 28'
Blinman	(South Aust.)	31° 12'	138° 37'
Boyes' River	Huntley 73	42° 40'	146° 14'
Broken Hill	(New South Wales)	30° 58'	141° 21'
Buffelsdorp	(South Africa)	26° 29'	27° 22'
Cape Grim	Three Hummock 13	40° 41'	144° 41'
Colbinabbin	(Victoria)	36° 45'	144° 45'
Comstock	Lyell 58	42° 02'	145° 39'
Coongan River	(Western Aust.)	21° 50'	118° 45'
Corinna	Corinna 43	41° 39'	145° 37'
Daly River	(Northern Territ.)	14° 00'	130° 40'
Dial Range	Devonport 29	41° 11'	146° 01'
Didicoolum	(South Aust.)	36° 24'	140° 12'
Double Cove	Macquarie Hbr. 64	42° 20'	145° 20'
Duck Bay	Smithton 21	40° 50'	145° 04'
Dundas	Zeehan 50	41° 53'	145° 28'
Edith River	(Northern Territ.)	14° 08'	132° 15'
Elandsfontein	(South Africa)	26° 28'	27° 25'

Florentine River	Huntley 73	42° 35'	146° 27'
Grassy River	S.E. King Is. 10	40° 03'	144° 04'
Groom's Slip	Devonport 29	41° 07'	146° 06'
Gunn's Plains	Sheffield 37	41° 18'	146° 01'
Hamilton Range	Gordon 72	42° 39'	145° 58'
Hawker	(South Aust.)	31° 55'	139° 40'
Heathcote	(Victoria)	37° 03'	144° 38'
Heazlewood	Magnet 35	41° 30'	145° 18'
High Rocky Point	Montgomery 78	42° 46'	145° 23'
Howqua River	(Victoria)	37° 20'	146° 15'
Jamieson River	(Victoria)	37° 20'	146° 12'
Kimberley District	(Western Aust.)	18° 00'	125° 00'
King Island	-	39° 35'- 40° 16'	143° 50'- 145° 17'
King River	Strahan 57	42° 10'	145° 30'
Kingston	(South Aust.)	36° 54'	139° 40'
Kilmore	(Victoria)	37° 22'	144° 55'
Klerksdorp	(South Africa)	26° 53'	26° 41'
Kolomesplaas	(South Africa)	26° 37'	27° 07'
Kuruman River	(South Africa)	27° 00'	21° 00'
Lake Margaret	Murchison 51	42° 01'	145° 37'
Lassen Peak	(U.S.A.)	42° 00'N.	106° 00'W.
Leven Gorge	Devonport 29	41° 15'	146° 10'
Long Plain	Corinna 43	41° 32'	145° 13'
Lucy River	Corinna 43	41° 38'	145° 08'
Lynch Creek	Lyell 58	42° 07'	145° 33'
Mackintosh River	Mackintosh 44	41° 43'	145° 37'

Macquarie Harbour	Macquarie Hbr. 64	45° 15'	145° 25'
Magnet	Magnet 35	41° 28'	145° 26'
Mainwaring River	Rocky Point 79	42° 49'	145° 32'
Marcollat	(South Aust.)	36° 15'	140° 27'
Mashowing River	(South Africa)	26° 25'	22° 20'
Medicine Lake Highland	(U.S.A.)	42° 00'N.	106° 00'W.
Monegetta	(Victoria)	37° 25'	144° 40'
Montana	Zeehan 50	41° 51'	145° 17'
Montezuma Falls	Zeehan 50	41° 51'	145° 27'
Mt. Arrowsmith	(New South Wales)	30° 22'	141° 33'
Mt. Chester	Mackintosh 44	41° 42'	145° 32'
Mt. Claude	Sheffield 37	41° 30'	146° 12'
Mt. Darwin	Lyell 58	42° 16'	145° 36'
Mt. Farrell	Mackintosh 44	41° 44'	145° 34'
Mt. Jukes	Lyell 58	42° 11'	145° 36'
Mt. Lyell	Lyell 58	42° 03'	145° 37'
Mt. Ramsay	Corinna 43	41° 36'	145° 27'
Mt. Read	Murchison 51	41° 53'	145° 33'
Mt. William	(Victoria)	37° 22'	142° 22'
Mt. Wright Mine	Corinna 43	41° 30'	145° 16'
Mull	(Scotland)	56° 25'N.	6° 00'W.
Murchison River	Murchison 51	41° 51'	145° 42'
Naracoopa	Sea Elephant 6	39° 54'	144° 05'
North Pine River	(Queensland)	27° 15'	153° 00'
Nullagine	(Western Aust.)	21° 43'	120° 12'

Oakover River	(Western Aust.)	21° 15'	121° 00'
Old Pallas (Limerick)	(Ireland)	53° 36'N.	9° 20'W.
Oraparinna	(South Aust.)	31° 35'	138° 40'
Papineau Rocks	(South Aust.)	36° 56'	140° 05'
Paralana	(South Aust.)	30° 32'	139° 35'
Penguin	Devonport 29	41° 07'	146° 06'
Pieman River	Corinna 43	41° 50'	145° 20'
Pilbara	(Western Aust.)	21° 09'	118° 16'
Potchefstroom	(South Africa)	26° 30'	27° 40'
Quamby Brook	Quamby 46	41° 33'	146° 47'
Que River	Mackintosh 44	41° 36'	145° 31'
Queenstown	Lyell 58	42° 05'	145° 33'
Renison Bell	Zeehan 50	41° 48'	145° 25'
Ring River	Zeehan 50	41° 48'	145° 28'
Rosebery	Murchison 51	41° 47'	145° 33'
Rustenberg	(South Africa)	25° 39'	27° 48'
Salisbury District	Beaconsfield 30	41° 12'	146° 50'
Shaw River	(Western Aust.)	21° 00'	119° 45'
Sheku	(China)	30° 00'N.	108° 15'
Smithton	Smithton 21	40° 41'	145° 06'
Spero River	Point Hibbs 71	42° 38'	145° 21'
Styx River	Styx 81	42° 51'	146° 30'
Tarentaal	(South Africa)	26° 40'	27° 11'
Trial Harbour	Zeehan 50	41° 56'	145° 10'
Tullah	Mackintosh 44	41° 43'	145° 38'

Tyndall Range	Murchison 51	41° 56'	145° 38'
Victoria River	(Western Aust.)	15° 30'	130° 00'
Vyfhock	(South Africa)	26° 40'	27° 11'
Wanderer River	Point Hibbs 71	42° 43'	145° 25'
Wilson River	Corinna 43	41° 44'	145° 30'
Wooltana	(South Aust.)	30° 38'	139° 25'
Yellowstone National Park	(U.S.A.)	45° 00'N.	110° 00'W.
Yule River	(Western aust.)	21° 12'	118° 24'
Zeehan	Zeehan 50	41° 53'	145° 21'
Zeerust	(South Africa)	25° 36'	26° 06'

DESCRIPTION OF PLATES.

Plate 1.

Fig. 1. - Picrite basalt from Beaconsfield showing phenocrysts of olivine pseudomorphed by calcite and haematite. The light coloured patch is calcite and is not a pseudomorph.

Fig. 2. - "Breccia" from Lynch Creek. The dark fragments of glass with phenocrysts of pyroxene and plagioclase are portions of the chilled surface which became fractured and caught up in the still molten lava, now represented by the light coloured portion of the rock.

Plate II.

This and the following plate illustrate the various stages in the development of the secondary spherules of quartz:

Fig. 1 - Illustrates one of the first stages in the development of the spherules. The quartz is beginning to take on a feathery form. The bulk of the mineral grains in this figure is of quartz with a few altered felspar laths and some chlorite.

Fig. 2. - The space between the spherules is filled with very fine granular quartz. Note the narrow

radial fringe of quartz around the margins of the spherules.

Fig. 3. - Shows the development of the radial fringes of quartz (see figure 2) at the expense of the fine granular material, some of which is still to be seen in the centre of the newly developed spherule.

<u>Plate III.</u>

Fig. 1 - In this case the fine grained material increased in grain size and at the same time the radiating fringes grew out. At the junction of the two a circular crack developed.

Fig. 2. - Illustrates the formation of two spherules which began to grow from the inside as well as the outside resulting in the formation of a crack where the two met.

Fig. 3 - Illustrates the final stage when the whole rock has been converted to a mass of spherules with very little or no granular material between them.

<u>Plate IV.</u>

Fig. 1 - An outcrop in the field of the hornblende andesite (?) showing the large cognate xenoliths of the chilled surface.

Fig. 2. - An outcrop showing the flow structure.

Fig. 3. - A closer view of the outcrop (figure 2) showing the alignment of the hornblende "phenocrysts".

Plate V.

Figures in this plate illustrate the formation of the idioblasts of hornblende from augite in the hornblende andesite (?).

Fig. 1. - A phenocryst of diopsidic augite showing alteration to chlorite, epidote etc.

Fig. 2. - A phenocryst of the augite which has been completely altered to chlorite and sphene etc.

Fig. 3. - Idioblast of hornblende which has grown out of the alteration products of the augite. Note the presence of these products as inclusions in the hornblende.

Plate VI.

Fig. 1. - Idioblast of quartz in the hornblende andesite (?) showing the fine grained "replacement border" and inclusions of the groundmass.

Fig. 2. - Idioblasts of quartz growing out of patches of quartz in the groundmass of a porphyroid from Dundas.

Plate VII.

Fig. 1. - Radiating sheaves of clinozoisite and the idiomorphic phenocrysts of pyroxene (?) pseudomorphed by chlorite and clinozoisite, in the Ongeluk lava from Vyfhock, South Africa.

Fig. 2. - Shows the pseudomorphs of clinozoisite after pyroxene and plagioclase in a dark devitrified glassy base. The lighter coloured patches are the silicified areas.

PLATE I

Figure 1 X55

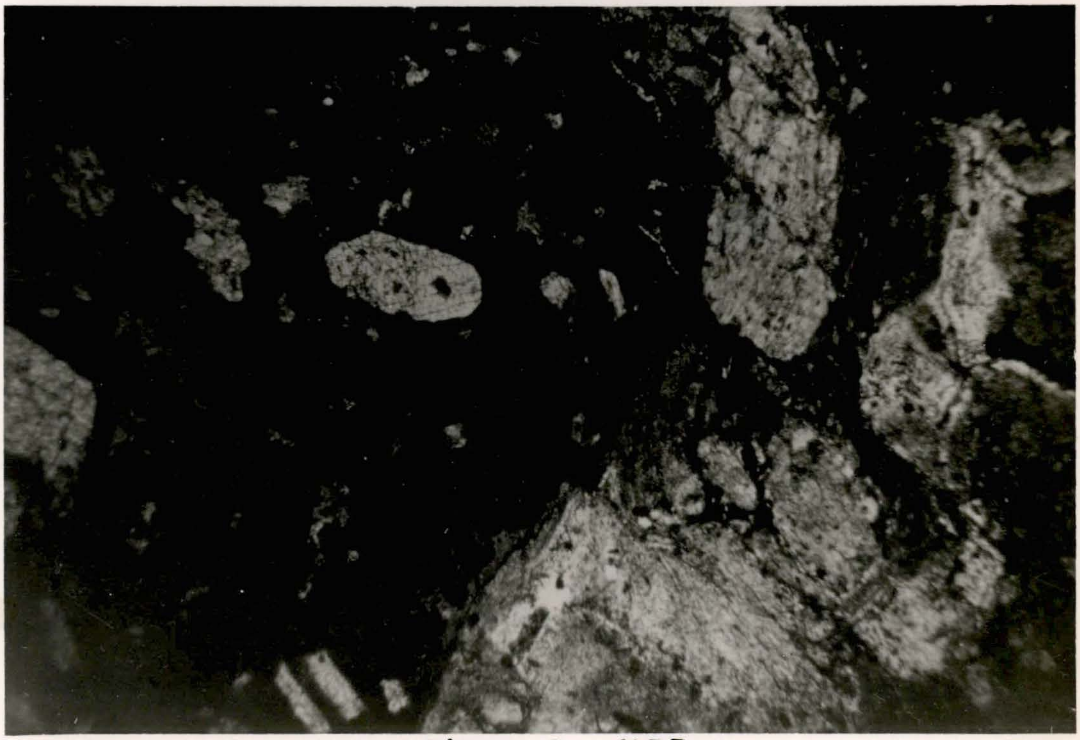

Figure 2 X55

PLATE II

Figure 1 X 40

Figure 2 X 40

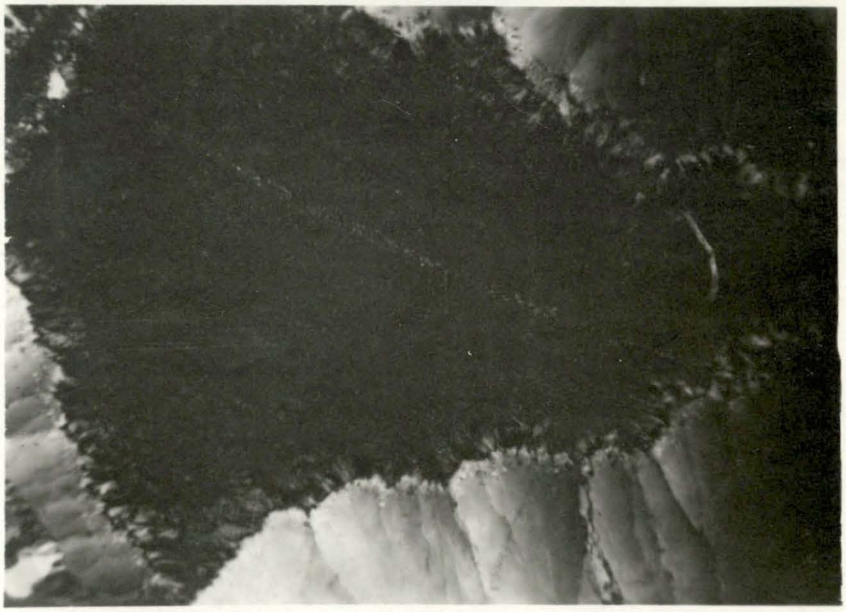

Figure 3 X 40

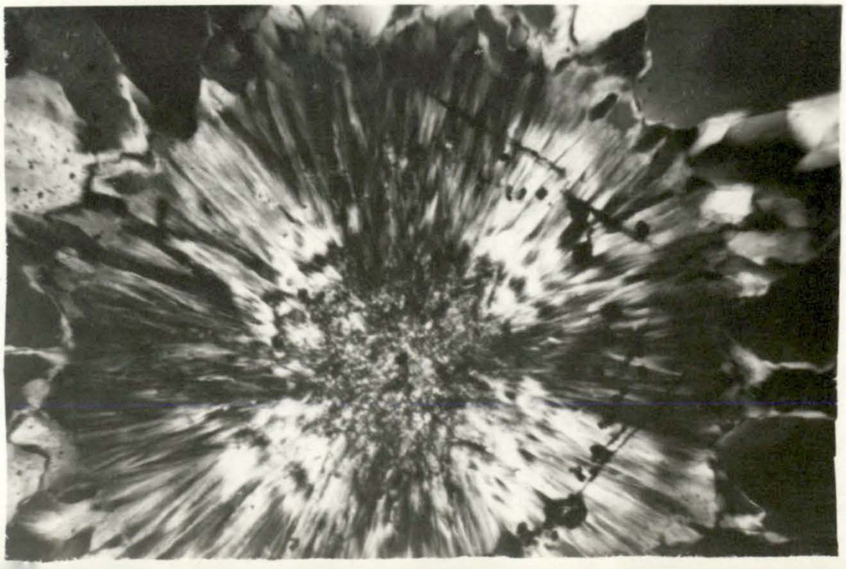

PLATE III

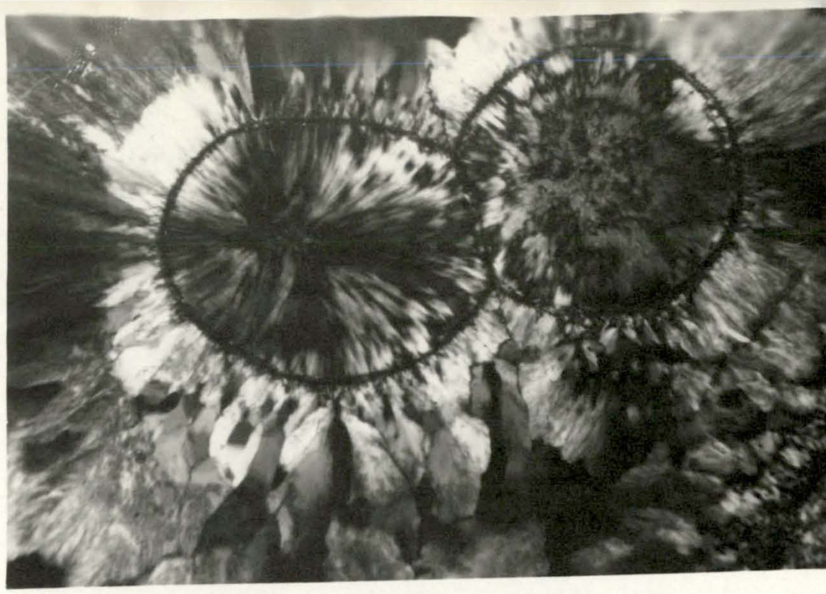

Figure I X40

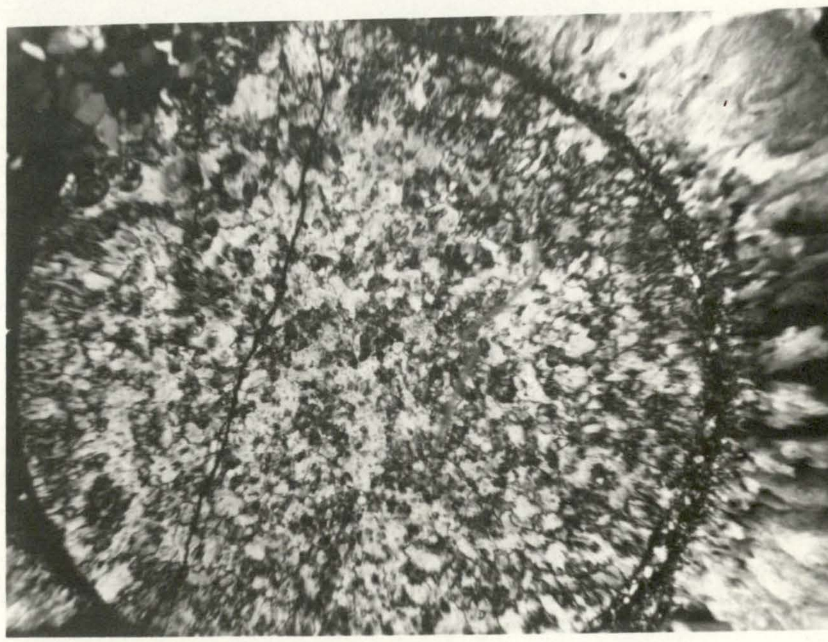

Figure 2 X40

Figure 3 X40

PLATE IV

Figure 1

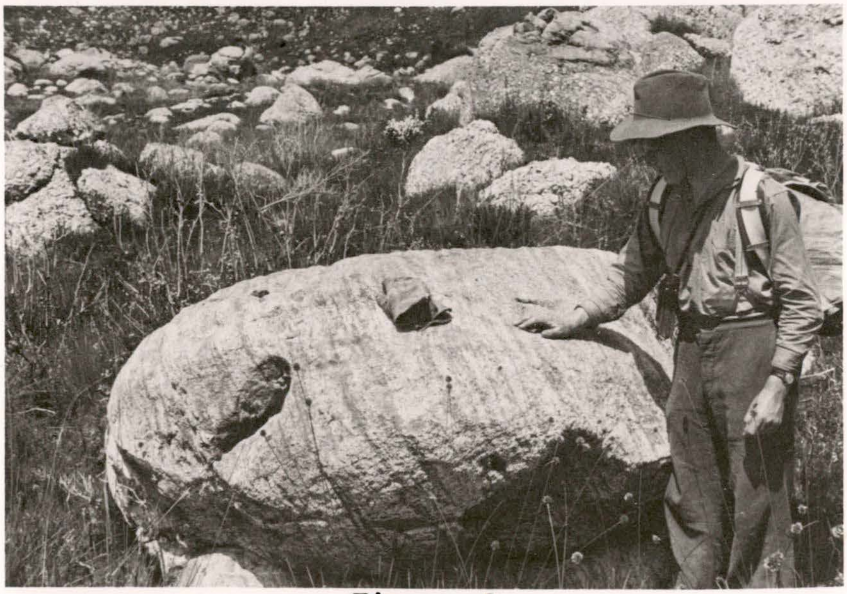

Figure 2

Figure 3

PLATE V

Figure 1 X40

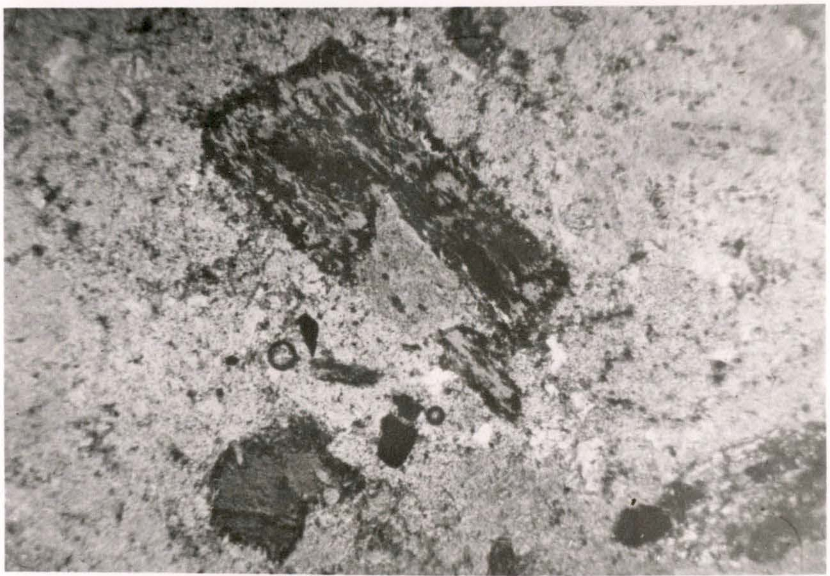

Figure 2 X40

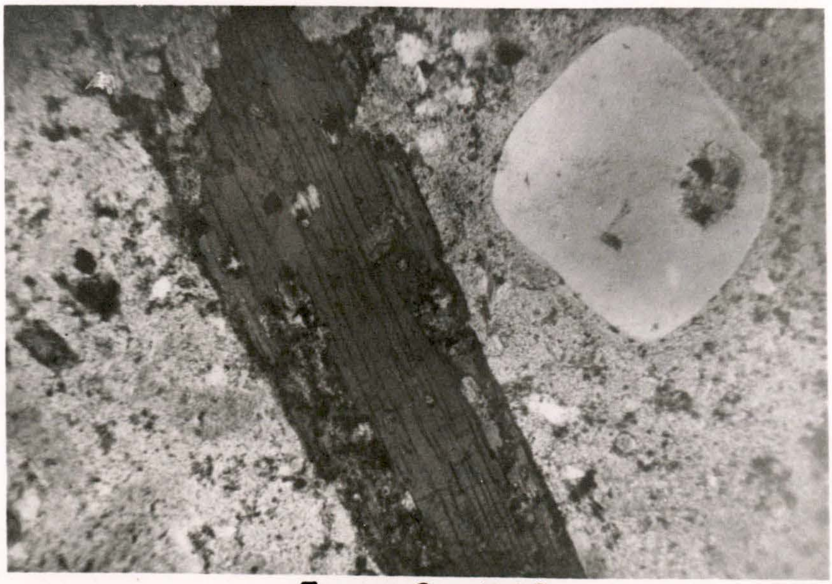

Figure 3 X40

PLATE VI

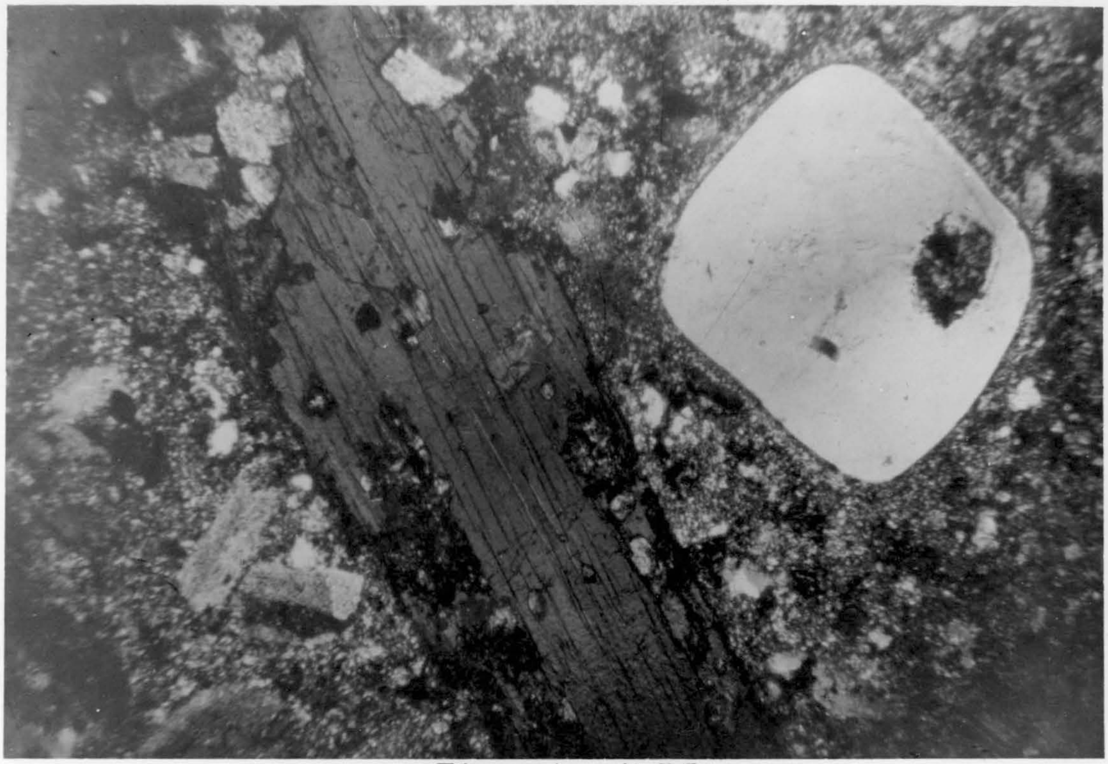

Figure 1 X 55

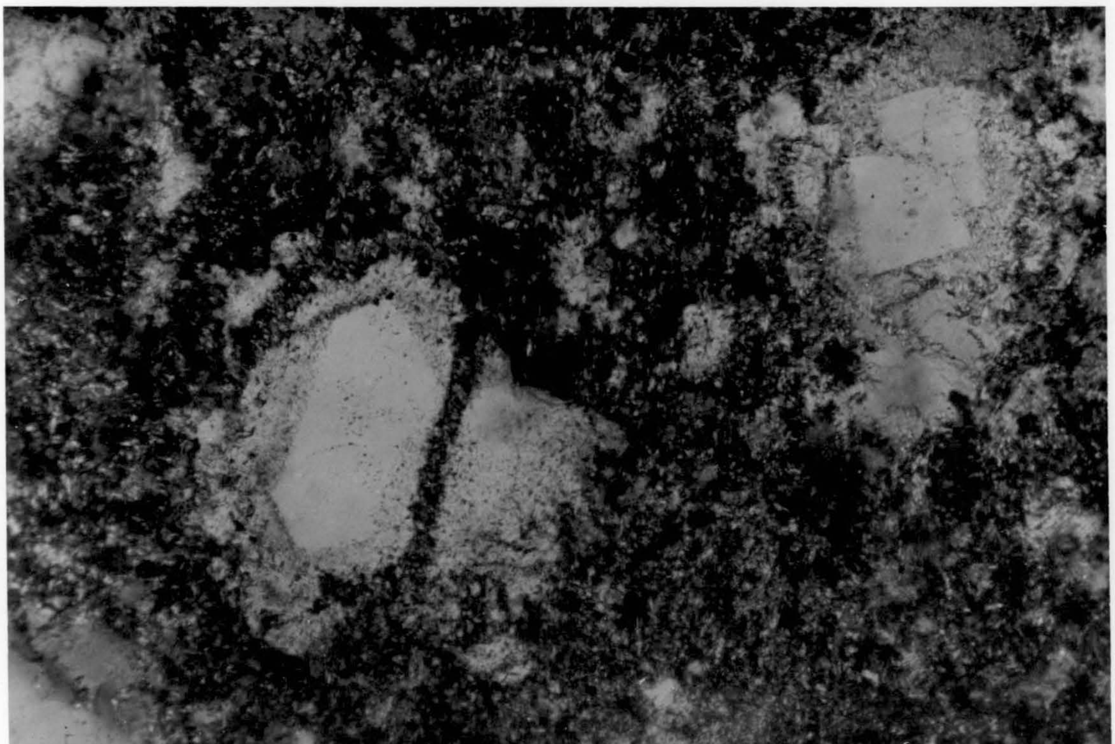

Figure 2 X 100

PLATE VII

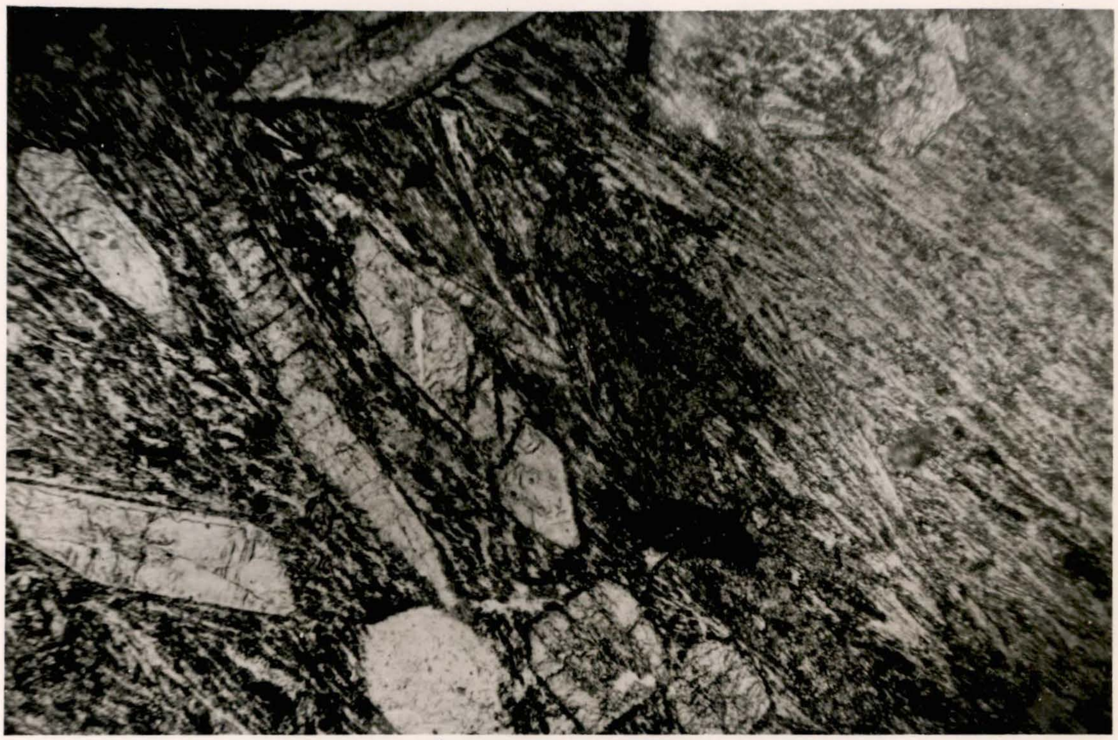

Figure I X 55

Figure 2 X100

APPENDICES

DEPARTMENT OF GEOLOGY
UNIVERSITY OF TASMANIA

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THE PETROLOGY OF THE VOLCANIC ROCKS OF SOUTH EAST KING ISLAND, TASMANIA

by

BERYL SCOTT, B.SC.

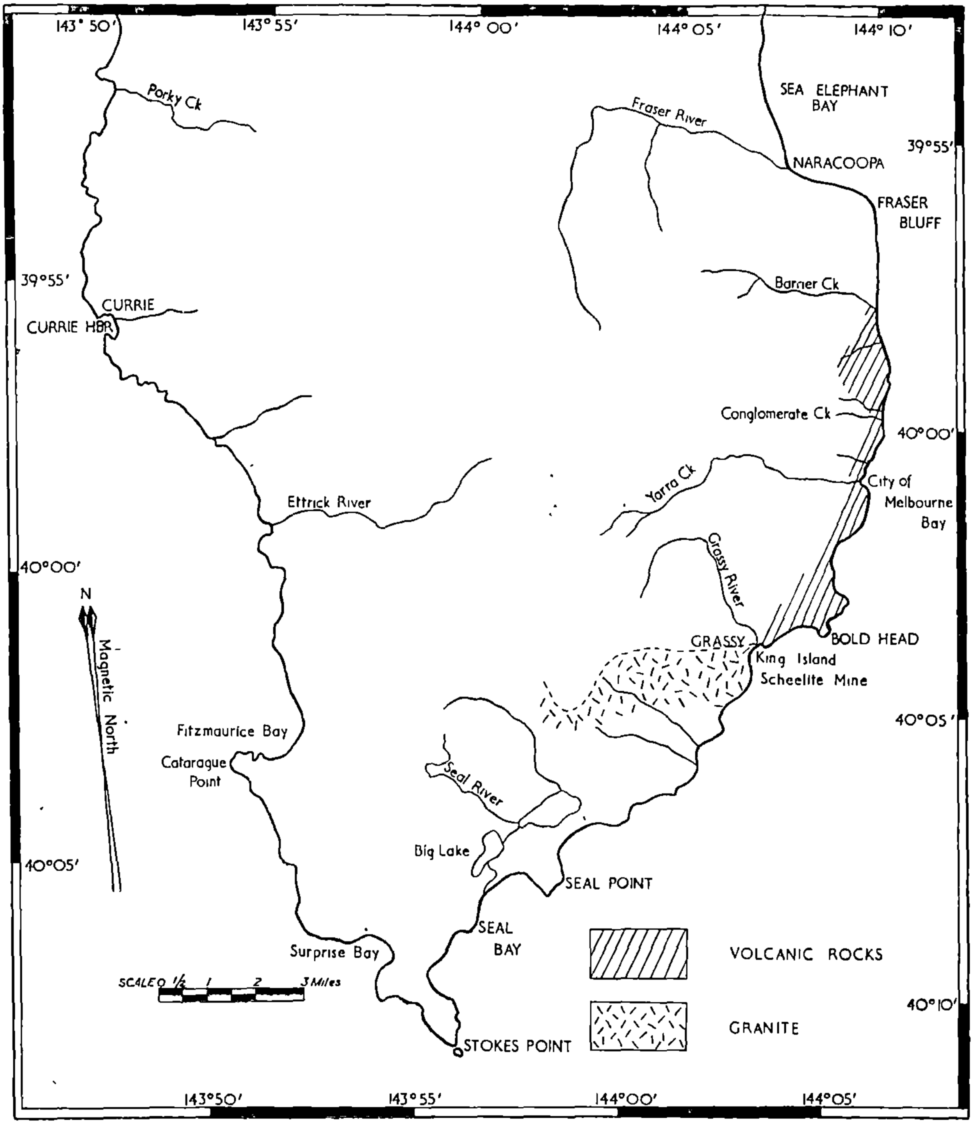
Hobart, 1951

The Petrology of the Volcanic Rocks of South East King Island, Tasmania

By

BERYL SCOTT

Fig. 1.



Southern portion of King Island showing the locality of the Volcanic Suite.

PAP. & PROC. ROY. SOC. TASMANIA, 1950 (15TH DECEMBER, 1951)

The Petrology of the Volcanic Rocks of South East King Island, Tasmania

By

BERYL SCOTT

WITH 6 PLATES AND 2 TEXT FIGURES

ABSTRACT

Spilites and picrite basalts in the form of massive, pahoehoe, aa and pillow lavas comprise the greater part of a volcanic suite, presumed to be Middle Cambrian in age, which outcrops along the south eastern coast of King Island, Bass Strait, Tasmania, Australia In the spilites the augite is unusually fresh and in the associated breccia fragments of undevitrified volcanic glass still exist It has been suggested that some of the albite may be primary because of its ophitic relation and intergrowth with the augite The results of both late magmatic and post magmatic alteration have produced an interesting assemblage of minerals including hydrogrossular which has not been described before in a similar context.

INTRODUCTION

The suite of volcanic rocks under consideration crops out along the south-east coast of King Island, Bass Strait, Australia. It extends for a distance of about 8 miles from Barrier Creek in the north to Grassy (latitude 40° 3′ S, longitude 144° 4′ E) in the south where it is probably terminated by a fault along the Grassy River.

The rocks dip about 40° to the east and strike approximately N. 10° E. Here and there they have been dislocated by small faults, striking usually about 290°-300°, which have prevented relatively accurate determination of the thickness of them. However, it is estimated that the volcanic suite has a greater thickness than 1000 feet.

The volcanic rocks are associated with tillite and varve. The greater part of the suite overlies these glacials but some of the basal members underlie them or are even interbedded with the varves.

Scattered over the island are outcrops of granite which seem to indicate that the whole island is underlain by this rock type. At Grassy the volcanic rocks have most probably been intruded by granite but unfortunately the contact has been concealed because of faulting and a recent covering of sand dunes.

AGE

In 1910 Debenham noted the occurrence of basalt south of the Fraser River and basic tuff at City of Melbourne Bay but ascribed a Tertiary age to them and correlated them with the Tertiary eruptives of Western Victoria. Then in 1915, Waterhouse recorded a brief description of an intensely altered series of basic and acid igneous rocks and igneous breccias and tuffs along the south-east coast of the island. He classed them tentatively as Cambro-Ordovician in age because of their similarity to the porphyroids on the West Coast of Tasmania. Because of the associated tillite and dolomitized varve, Carey (1946) correlated the series with the Zeehan glacials and Montana melaphyre volcanics of Tasmania and assigned them to the Pieman Group of rocks of Upper Proterozoic to Cambrian (?)

in age. At Dundas Trilobites, determined by Opik* to be Upper Middle Cambrian in age, have been found in rocks interbedded with the Curtin Davis lavas reputed to be similar to those at Zeehan. West of Zeehan Trilobites, Brachiopods and Cystoids have been found in 'keratophyre tuffs' which overlie the Montana melaphyres and glacials. These fossils indicate an upper Middle Cambrian age for these rocks in this area. If the King Island volcanics are equivalent to those at Zeehan then their age may be stated as Upper Middle Cambrian.

However, the age of these volcanic rocks still remains a moot problem. No fossils have been found in the underlying sediments. If the age of the glacial beds is late Pre-Cambrian or very early Cambrian or even Upper Middle Cambrian then the volcanics are as old because they are so intimately related.

Although the presence of glass in the tuffs would seem to indicate a much younger age, the suite is definitely older than the granite, by which the rocks are affected, and this granite is most probably of lower Palaeozoic age.

Mode of Occurrence and Rock Types

In the field these volcanic rocks are quite striking and in spite of the great age which has been imposed upon them appear to be unusually fresh, so much so that they look as if they could have just issued from a volcano. This fact is well illustrated by the photographs in Plates I and II.

The forms of flow taken by the lavas are massive, one example showing columnar structure, aa or block, pahoehoe or ropy, and pillow. As well there is an accompanying group of fragmental rocks. Here and there narrow dykes intrude the suite. Generally speaking, the field form serves as a rough kind of classification for the rock types. Each form seems to have its own rock type with its particular kind of crystallization and mineral constituents. These will be described below.

The sequence of types overlying the glacials appears to be breccia and massive lava followed by aa, pahoehoe, and pillow, the resulting rock being in accordance with the prevailing conditions at the time of eruption. Showers of tuff were probably ejected throughout the period of vulcanicity.

Massive Lavas

These are normal flows of lava of varying thicknesses and seem to be the basal lavas of the series. Massive lavas occur below the glacial beds, interbedded with the varves and immediately overlying the glacials.

The rock is a spilite in composition and either appears as a normal looking basalt or a basaltic type with an extremely ophitic texture.

The type resembling a typical basalt (see Plate IV, figure 3) consists of laths of plagioclase and small grains of augite and magnetite. The plagioclase is almost pure albite, $Ab_{98}An_2$, and in parts shows alteration to chlorite and kaolin. The augite is surrounded by borders of a brown coloured mineral, otherwise it is relatively fresh. In some sections where the augite grains are larger, zoning and incipient hour-glass structure are present. Chlorite is abundant and appears in the interspaces of the plagioclase laths and augite granules. A little epidote in the form of small grains and patches of calcite, varying in abundance are also present. Sometimes small circular vesicles are present and these have been filled with chlorite and epidote.

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* Personal communication from Mr M R Banks, palaeontologist, Geology Department, University of Tasmania who accompanied Dr. A A Opik of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australian Capital Territory, in the field. Stratigraphy from unpublished work of J N. W. Elliston.

A coarser phase, doleritic in texture, but mineralogically the same, exists. Ilmenite is found surrounding patches of analcite. An interesting feature about this rock is that it shows evidence of slight metamorphism in the clouding of the felspar. Tiny needles of tremolite are found extending along the edges of the plagioclase crystals at right angles to the edges and pointing inwards.

The other type of massive lava is the one consisting of large plates of augite which are pierced by small laths of plagioclase. The augite is colourless, has good cleavage and is extremely fresh except for alteration to a brown mineral around the edges. The birefringence is ·030. The mineral is biaxial positive with an optic axial angle of 51° and an extinction angle of 40°. These properties indicate a diopsidic variety. Some of the large plates of augite have been so broken up by the presence of the plagioclase that they appear to consist of numerous small augite grains and it is not until the mineral is observed under analysed light that it is realized the mineral plate is homogeneous. This ophitic fabric is depicted in Plate V, Fig. 3. The plagioclase is albite and has been altered to sericite and contains patches of minute brown granules of hydrogrossular. Also present in the groundmass are granules of brown sphene, epidote, quartz, and calcite.

Another phase of this type of basalt gives rise to an unusual and interesting rock. Microscopically the rock consists for the most part of two minerals, diopsidic augite and a felspar which has been mostly pseudomorphed by sericite and some chlorite, although small patches of the unaltered albite remain. As usual the diopside is quite fresh and has similar properties as described above. Cleavage is strong and continuous and in some sections two at 90° are seen. The augite forms homogeneous plates which are broken only by the presence of the plagioclase.

The amazing feature of the rock is that the diopside and albite form perfect intergrowths covering the whole field of the microscope. (See Plate V, Figs. 1 and 2.) Occasionally between the areas of graphic intergrowth is to be found epidote. The author is unaware of a description of a similar phenomenon in the geological literature read.

Two questions are raised by the occurrence of such an intergrowth. First, is the structure an exsolution structure or secondly is it a true eutectic? The possibility of an exsolution structure can be neglected because the whole mass of rock is composed of such a structure and apparently is a feature of primary crystallization, probably formed at a later stage in crystallization following the formation of the ophitic fabric. This primary crystallization structure is the answer to the second possibility, that is a eutectic structure, and will be discussed in some detail later.

Pillow Lavas

These lavas have the typical ellipsoidal form of pillow lavas. The pillows vary from one to six feet in diameter. Each has a chilled margin of about half to one inch thick before a zone of radially arranged elongated vesicles filled with chlorite and other secondary minerals. Towards the centre the pillows show variolitic structure. Sometimes the material around the varioles has been weathered away leaving the varioles to stand out like marbles while at other times the varioles and surrounding material have weathered evenly, in which case the varioles are distinguished by their lighter colour. Examples of both types of weathering of varioles are shown in the photographs, Figs. 3 and 4 on Plate I. In some instances the surface of the pillow has a ropy structure.

The type of rock present is photographed in Plate IV, Fig. 4. It consists of a few idiomorphic laths of plagiclase up to 1 mm. in length and a few subidiomorphic phenocrysts of fresh augite in a groundmass of feathery augite and plagioclase and some granules of epidote and magnetite. The plagioclase is albite some of which shows no or only simple twinning. Some of the larger crystals show alteration in part to chlorite. Small vesicles lined with epidote and filled with chlorite are present. Other vesicles, lined with chlorite and/or epidote, are filled with quartz. The rock is traversed by very fine veins of secondary minerals, epidote, quartz, and calcite.

Pahoehoe (ropy) lavas

This lava type is found in irregular flows varying from 6 to 18 inches in thickness, each having a chilled surface and base. See Plate II, Figs. 3 and 4.) The surface of some flows reveals beautifully preserved ropy structure as illustrated in Fig. 3, Plate III. In the field some of the pahoehoe type of lava appears to be so contorted that it grades into the pillow type of lava. The chilled margin is about one inch in thickness and grades into a zone very rich in vesicles and then in some cases to a region of variolitic structure.

The crystallization of the pahoehoe lava varies from the surface of the flow towards the centre. The top section is very fine grained and contains minute crystals of augite and plagioclase with a few phenocrysts of olivine, now pseudomorphed by chlorite. Vesicles are very abundant and are mostly elongated more or less parallel to the top of the flow and average about 1·5 to 2 mm. in length. In some specimens the vesicles are circular or oval in shape, filled with chlorite and are so numerous that the name 'bile bean rock' has been given. This vesicular and fine grained type passes downwards into a type where vesicles are less numerous and olivine pseudomorphs are wanting. The augite and plagioclase have increased in size. The plagioclase is lath shaped and the augite is arranged in sheaf-like masses of radiating crystals. (See Fig. 2, Plate IV.) Most pahoehoe types fall into this general description but the alteration in some has been different.

In some, the vesicles have been filled by chlorite and epidote and in others by calcite, prehnite or albite. In most cases the plagioclase is albite and shows alteration to chlorite and hydrogrossular while the augite, on the other hand, has remained relatively fresh. Prehnite and sericite, albite, quartz, chlorite, epidote and hydrogarnet are to be found in the vesicles and interspaces in the coarser grained parts. It seems as though in the various pahoehoe lavas that either chlorite is the predominant infilling mineral when hydrogarnet is more abundant or prehnite when hydrogarnet is less abundant. Sometimes where the quartz has come in contact with the augite fine needles of tremolite, pointing into the quartz, are developed about the augite. Also there is a concentration of iron in the pyroxene along the tips of the crystals. Amongst the pahoehoe lavas is an excellent example of granules of hydrogrossular replacing olivine. (Plate VI, Fig. 3.) In some specimens some of the augite has been replaced by numerous tiny granules of pale green chlorite.

Aa (block) Lavas

These seem to merge from and into the pahoehoe and pillow lavas. Stray pillows, budding into each other by means of necks, as illustrated in Plate II, Fig. 1, are found amongst the block lavas. The blocks are irregularly shaped and vary in size, an average size being 4 to 5 inches. The surfaces are often irregular, shiny and iron stained. In general the block lava is a porphyritic rock consisting of phenocrysts of olivine, now pseudomorphed by almost colourless chlorite, in a very fine grained greyish coloured groundmass. (See Plate IV, Fig. 1.) The phenocrysts vary in size up to 1·3 mm. and in some cases are grouped together to give the rock a glomeroporphyritic texture. The crystals, on the whole, are idiomorphic and it was by the crystal outline and apical angle that the original mineral was determined to be olivine as there is no trace of the original mineral remaining. The form of the chlorite which is pseudomorphing the olivine is in aggregates of fibrolamellar structure. Its refractive indices were determined to be $\alpha = 1{\cdot}591$, $\gamma = 1{\cdot}594$. The mineral is biaxial positive and length slow. X-ray powder photography verified that it is of the pennine variety with the three strongest interplanar spacings being 7·146, 3·558 and 4·736. Pointing inwards from the sides of the chlorite and arranged haphazardly in the phenocrysts are needles of colourless to very pale green tremolite, ranging up to ·25 mm. in length. Some of the phenocrysts show patchy alteration to brown hydrogrossular. As illustrated by Fig. 4 on Plate VI. In other cases, however, the hydrogrossular has completely pseudomorphed the olivine crystals. In some sections it appears as if some pyroxene phenocrysts were present as well as olivine. These have been completely pseudomorphed by chlorite but definite cleavage traces still remain.

The groundmass is very fine grained, in some specimens probably devitrified glass, and is blotchy grey in colour. Under high power it is found to consist of fibrous needles of colourless tremolite and tiny patches showing incipient crystallization of pyroxene, most probably pigeonite. An attempt was made by X-ray powder photography to determine the type of pyroxene but many difficulties were encountered because of the nature of the mineral, its extremely fine crystallinity and its relationship with tremolite. However, a photograph was taken of the powdered groundmass and after elimination of the tremolite lines, the identity of the remaining mineral was determined as a clinopyroxene, possibly pigeonite. Because of its form the pyroxene gives anomalous optical properties. For the most part, the crystals are length slow, although some are length fast. It is optically positive with a rather small optic axial angle. After much difficulty the refractive indices were determined as $\alpha = 1{\cdot}629$ and $\gamma = 1{\cdot}653$ but the correctness of these cannot be vouched for due to the impossibility of separating the pyroxene from the tremolite. Persistent fringes of tremolite adhered to the pyroxene. Extinction appeared to be straight but again this may be due to the nature of the crystals.

In the groundmass and occasionally in the phenocrysts are to be found very small cubic crystals of the brown spinel, picotite.

Occasionally vesicles are found and these are filled with chlorite or hydrogrossular. When the latter mineral fills the vesicles it is darker towards the edge and very pale brown towards the centre as seen in Fig. 4 of Plate VI. The refractive index increases from the edge towards the centre.

Perhaps the 'shower droplet' rock could be described under this heading, not because it could be classed as a block lava but because it too is a picrite basalt as above. This 'shower droplet rock' occurs in a bed of about 2 feet thickness. It resembles a bed of conglomerate especially on a weathered surface but closer examination of a non-weathered section reveals a certain amount of welding together of the lapilli. Two photographs, Figs. 1 and 2, of this rock appear on Plate III. Apparently this rock type has developed close to the vent of the volcano and is the result of the accumulation of small drops of lava or lapilli which have dropped one on top of the other when almost, though not completely, solidified. Only one example has been found and it occurs just north of the outcrop of tillite north of Conglomerate Creek. Microscopically it contains idiomorphic phenocrysts of olivine pseudomophed by chlorite and brownish green coloured iddingsite along the cracks and around the edges. A few small oval shaped vesicles filled with chlorite, some of which is radiating, are present. The groundmass is so finely crystalline that it is impossible to distinguish the mineral constituents. Small crystals of picotite are present. Between the small lapilli of lava which average half an inch in diameter is to be found colourless to very pale green pleochroic chlorite.

Fragmental Rocks

Breccia and tuff are found interbedded with the lavas and also between some of the pillows where they are banded and are very tough. In keeping with the lavas they are green in colour.

Generally the breccia consists of fragments of glass which is light brown or green in colour. The fragments are often irregularly cracked and some have been altered to colourless chlorite or a very dark green fibrous variety, possibly garnierite, the nickel bearing chlorite. The presence of nickel is not surprising because tiny flakes of pale, copper pink coloured niccolite were found in varved shale on the southern headland of City of Melbourne Bay. Epidote crystals and granules are usually present and are abundant along cracks and boundaries of the glass fragments. In many cases the glass has been altered to dark brown hydrogrossular, the alteration usually commencing around the edges and proceeding inwards until the whole fragment has been altered as depicted in Plate VI, Figs. 1 and 2. Other pieces of the glass show complete devitrification to fine grained rock or in another case the glass seems to pass over to quartz crystals. In some of these glassy breccias a few pseudomorphs of chlorite and hydrogarnet after olivine are present, also some crystals of picotite.

The presence of glass in this volcanic suite is an unexpected feature because of its age and its resistance to hydrothermal solutions. Specimens have been found in which the glass is very dark green in colour, highly vitreous, and shows conchoidal fracture like obsidian. Its refractive index was determined as 1·6927 and its specific gravity as 2·49. The chemical composition of this glass will be discussed later.

The tuffs between the pillows and other banded tuffs are very fine grained and appear to consist of tiny fragmental grains of quartz, felspar and epidote and contain patches of calcite and chlorite.

Dyke Rocks

The volcanic suite is traversed by numerous small dykes which seem to trend roughly in a north south direction at right angles to the fault pattern. In all cases they are only about 2 to 3 feet wide and from a few yards to 100 yards at the most in length.

Petrographically, for the most part, the rock type is much the same as in the volcanic suite, particularly the massive basaltic variety. In some cases large phenocrysts of plagioclase, now kaolinised and sericitized are present. The rock in one dyke has been altered to an epidosite consisting of epidote, quartz and chlorite. Veins of idiomorphic to subidiomorphic crystals of epidote and quartz containing needles of tremolite are present.

There is one exception to the general rock type and this is an olivine minette. The rock contains large phenocrysts of brown biotite showing strong pleochroism and cleavage and colourless olivine and augite surrounded by reaction rims of what appears to be a pyroxene. This reaction rim in turn is surrounded by a halo of small magnetite granules. The augite is distinguished from the olivine by its strong cleavage. The groundmass is holocrystalline and contains abundant light brown biotite showing strong pleochroism and birefringence. Crystals of a mineral, most probably a pyroxene, judging from the crystallographic outline, are replaced by light green chlorite surrounded by magnetite granules. Orthoclase is abundant but is slightly altered to kaolin and has taken on a brownish colour. Magnetite as well as forming haloes about the altered minerals is scattered throughout the groundmass. Needles of tremolite and apatite are abundant, also small grains of calcite. Only one dyke of this rock was found and it trended in a similar direction to the fault pattern. Mineralogically this rock is a misfit in the spilitic suite. Minettes, according to Johannsen (1931) are usually associated with rocks of the granite-syenite family. As the volcanic series is intruded by granite in parts and closely underlain by it in others, it is most probably that this dyke rock is related to the granite rather than the volcanic rocks. A later age than the volcanics, that is, post faulting, is indicated by the direction of the trend of the dyke.

Chemical Composition

According to the chemical analyses of the rocks there are two groups, a picrite basalt with a composition comparable with the intra Pacific or Oceanic type and a spilitic type.

Generally speaking the picrite basalts are those found in the pahoehoe and aa lavas and the spilites in the massive and pillow lavas.

In Table I the analysis of the picrite basalt is given and for comparison the average analyses of picrite basalt of Hawaii (Daly, 1933, p. 397) and oceanite of the world (Tyrrell, 1926, p. 131).

TABLE I.—ANALYSES OF PICRITE BASALTS

	I.	(a)	(b)
SiO_2	46·53	46·62	45 6
Al_2O_3	10·51	8 68	8·3
Fe_2O_3	·62	2·04	2·3
FeO	8·27	10·52	10·2
MgO	17 36	20 86	21·7
CaO	10·04	7·15	7·5
Na_2O	1·90	1·41	1·3
K_2O	22	·28	·4
H_2O+	3·71		
H_2O-	31	·23	·6
TiO_2	·21	1·71	1 7
P_2O_5	Tr.	·14	·3
Cr_2O_3		·12	
MnO	·16	·14	·1
NiO		·10	
Total	99·84	100·00	100·00
Norm			
Orthoclase	1 11		
Albite	16 24		
Anorthite	19 46		
Diopside	24·20		
Hypersthene	·33		
Olivine	33·02		
Magnetite	·93		
Ilmenite	·46		
Apatite			
Water	4·02		

I.—Picrite basalt (aa lava), King Island, Tasmania, Anal. B. Scott.
(a) Average picrite basalt of Hawaii according to Daly (1933) p. 397.
(b) Average oceanite of the world according to Tyrrell (1926) p. 131.

The spilitic types have been plotted on a triangular diagram (Fig. 2) on the basis of Na_2O, FeO and MgO (Sundius, 1930) and each of these rocks falls well within the area of spilites. The picrite basalt on the other hand falls well outside the area and on the true basalt side towards the base FeO, MgO of the diagram.

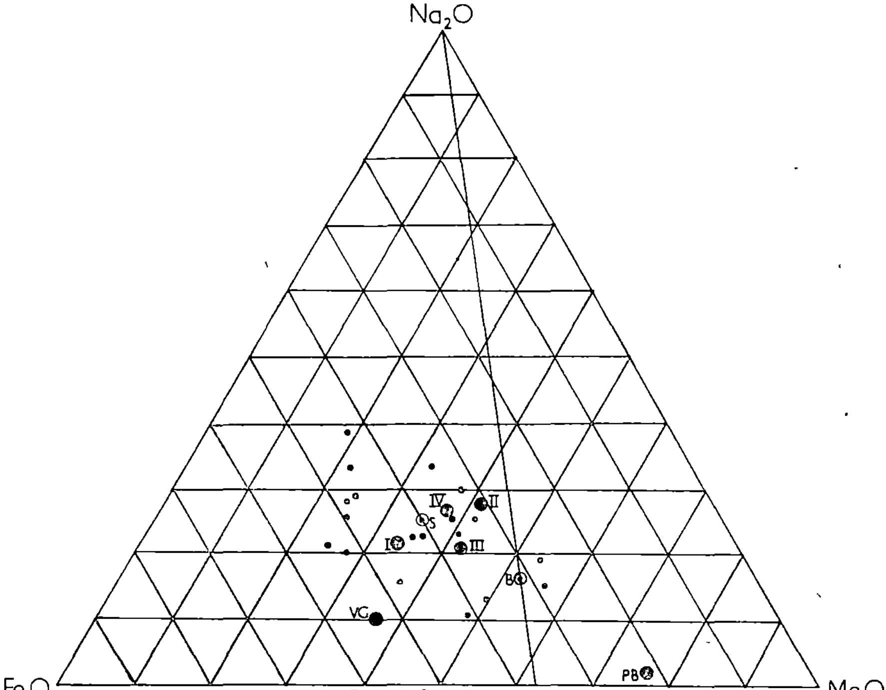

Figure 2 (After Sundius 1930)

- Spilites from various localities in the world as plotted on Sundius' original diagram
- ⊙ S Average Spilite
- I IV King Island Spilites
- PB Picrite Basalt King Island
- VG Volcanic Glass King Island
- ⊙ B Average Basalt

Four spilites were analysed and the results of the analyses are tabulated for comparison with those of a British spilite, an average spilite and two of Benson's (1915) in which the augite is also very fresh.

A glance at the analyses would indicate that the series is very rich in alumina, a fact which is illustrated again when the alteration of minerals is considered. The possible source of this alumina is discussed later. Low titanium is a feature of the rocks but nevertheless it is constant in the series. High potash in spilites I and II is probably due to the abundant sericitization of the felspar.

The analysis of the volcanic glass yielded an interesting result. It was hoped that the analysis showing the chemical composition of the glass would help to identify the nature of a parent magma of these lavas especially indicating whether it is a sodic or non sodic variety and at the same time to establish the fact as to whether the albite is primary or secondary. Contrary to expectation the glass is poor in the alkalis and magnesia but rich in lime and alumina for its silica content. Its position on the triangular diagram does at least indicate spilitic affinities. However, its composition does facilitate the explanation of some of the hydrothermal alteration. Perhaps the fact that this glass is so rich in lime helps to explain the stability of such an ancient glass.

TABLE II.—ANALYSES OF SPILITES

	I.	II.	III.	IV.	(*a*)	(*b*)	(*c*)	(*d*)
SiO_2	47·40	48·24	50·01	52·61	51·31	51·22	48·22	51·19
Al_2O_3	19·19	17·55	15·38	13·03	12·67	13·66	14·82	14·40
Fe_2O_3	1·48	1 05	4·86	3 90	·54	2·84	·56	4 43
FeO	8 26	7·04	9·21	8·48	7·99	9·20	9·25	9·04
MgO	3 60	5·27	5·85	5·10	2·19	4·55	5·58	4·51
CaO	11·25	10·43	6·35	7 26	8·17	6·89	8 81	6 05
Na_2O	3·40	5 58	4·77	5·60	5·21	4·93	4·95	4·18
K_2O	1·31	·97	·40	·42	·54	·75	·44	·78
H_2O+	3·32	2·88	2·60	1·65	·04	1·88	2·54	1·82
H_2O-	·34	·17	·23	·10	2·31		·15	·24
TiO_2	·29	·70	·73	·72	1·92	3·32	2·68	2·69
MnO	·13	·12	·21	·19	·45	·25	·23	·21
P_2O_5	n.dt.	·10	09	Tr.	·90	·29	·24	·40
CO_2		·11	·13	·05	6·15	·94	1·40	abs.
S				·08				
FeS_2					·30		·37	·19
Fe_7S_8					·17			
NiO							·03	—
Total	99 97	100 21	100 82	99 19	100·86	100 72	100·26	100·13

Norms	I.	II.	III.	IV.
Orthoclase	7·78	6·12	2·22	2·22
Albite	18·34	19 65	40·35	46·63
Anorthite	33·08	20 02	19 46	10 01
Nepheline	5·68	14·91		·28
Diopside	19·15	24·76	8·96	21·99
Hypersthene			7·20	
Olivine	19 05	7·74	11·18	9·76
Magnetite	2·09	1·62	6·96	5·57
Ilmenite	·61	1·37	1·37	1·37
Pyrite				·04
Apatite		·34	34	
Calcite		·20	·20	·30
Water	3·66	3 05	2·83	1·75

I. Spilite (Intergrowth type), King Island, Tasmania, Anal. B. Scott.
II Spilite (Ophitic type), King Island, Tasmania, Anal B. Scott.
III. Spilite (Basaltic type), King Island, Tasmania, Anal. B. Scott.
IV Spilite (Pillow lava), King Island, Tasmania, Anal. B. Scott.
(*a*) Spilite, West side of Tayvallich Peninsula, Argyllshire. Anal. E. G. Radley (Dewey & Flett (1911))
(*b*) Average spilite according to Sundius (1930), p. 9.
(*c*) Spilite Frenchman's Spur, Nundle, N.S.W., Benson (1915), p. 139.
(*d*) Quartz dolerite, Munro's Ck , N.S.W , Benson (1915) p. 139.

TABLE III.—ANALYSES OF VOLCANIC GLASS

	I.	(*a*)
SiO_2	44·14	47·57
Al_2O_3	15 63	14 85
Fe_2O_3	5·45	4·52
FeO	·93	8·28
MgO	2·75	7·33
CaO	20·44	8 99
Na_2O	80	3·93
K_2O	·21	1·03
H_2O+	6 04	1·70
TiO_2	·31	1 61
MnO	·11	
P_2O_5	n.dt.	·28
Total	100·81	100·09
Norm.		
Quartz	16·50	
Orthoclase	1·11	
Albite	6·81	
Anorthite	38·36	
Diopside	17·62	
Wollastonite	7·08	
Ilmenite	·61	
Magnetite	7 89	
Water	6·04	

I. Glass from breccia, King Island, Tasmania, Anal. B. Scott.
(*a*) Average analysis of 5 basaltic glasses from Washington (1917).

Identification of the fine grained tuff between the pillows was difficult microscopically because of the fineness of grainsize. However, chemical analysis has revealed that the rock is definitely a tuff of similar composition to its parent lavas and is not a banded chert, rich in silica, as one may be inclined to think because of its extreme toughness, hardness and field position.

SiO_2	51·14
Al_2O_3	9·01
Fe_2O_3	2·32
FeO	3·99
MgO	12·49
CaO	14·34
Na_2O	1·67
K_2O	·39
H_2O+	2 64
H_2O-	·20
TiO_2	·49
MnO	·16
P_2O_5	ndt.
CO_2	~~·18~~ ·90
Total:	99·74

Tuff, Between Pillows of Lava, King Island, Tasmania, Anal. B. Scott.

TRACE ELEMENTS

Spectrographic analyses for trace elements were carried out on several of the analysed rock specimens in the Department of Mineralogy and Petrology, University of Cambridge.

The results of these spectrographic analyses have been combined with the corresponding analyses and are tabulated in Table IV.

The amounts of each trace element are fairly constant in the volcanic suite and in keeping with the basicity of the rocks. They compare favourably with those in other rocks.

Chromium and nickel are low in the basaltic pillow lava varieties of spilites while copper is high in the pillow lava. Barium is highest in the ophitic type of spilite. The absence of tin is surprising. Has this tin been removed by hydrothermal solutions or was it originally absent?

TABLE IV.—TRACE ELEMENTS IN KING ISLAND ROCKS (Expressed in parts per million)

	I.	II.	III.	IV.	V.	(*a*)	(*b*)	(*c*)
SO_3						1,200		
P_2O_5		1,000	900			2,400	700	2,800
SiO_2	465,300	482,400	500,100	526,100	511,400	485,000	504,200	482,400
Al_2O_3	105,100	175,500	153,800	130,300	90,100	130,100	165,500	178,800
Ga_2O_3	*(<*6*)	*13*	*20*	*13*	*20*	*30*	*30*	*10*
Cr_2O_3	*804*	*329*	*29*	*44*	*659*	*2,000*	*600*	*500*
TiO_2	2,100	7,000	7,300	7,200	4,900	10,300	8,400	9,700
V_2O_3	*115*	*257*	*257*	*404*	*110*	*500*	*450*	
Fe_2O_3	6,200	10,500	48,600	39,000	23,200	14,300	5,200	31,600
Li_2O	*43*	*258*	*108*	*22*	*108*	*40*	*10*	*20*
MgO	173,600	52,700	58,500	51,000	124,900	129,100	73,100	75.000
NiO	*573*	*127*	*38*	*89*	*255*	*250*	*100*	*200*
CoO	*57*	*32*	*46*	*46*	*32*	*90*	*35*	*100*
CuO	*69*	*75*	*313*	(>*313*)	*31*	*200*	*200*	
FeO	82,700	70,400	92,100	84,800	39,900	91,700	96,100	59,500
ZnO						*60*	*70*	.
Sc_2O_3	*30*	*54*	*54*	*54*	*23*	*30*	*15*	*30*
ZrO_2	*	*20*	*40*	*40*	*27*		.	
MnO	1,600	1,200	2,100	1,900	1,600	1,900	700	1,300
Na_2O	19,000	55,800	47,700	56,000		20,300	15,600	25,500
Yt_2O_3	*(<*13*)	*19*	*25*	*38*	*(<*13*)			*3*
CaO	100,400	104,300	63,500	72,600	143,400	95,200	123,200	109,900
ThO_2						*30*	*60*	
La_2O_3	*	*	*	*	*			
SnO	*	*	*	*	*	*200*	*350*	*200*
PbO	*	*	*	*	*			
K_2O	2,200	9,700	4,000	4,200		4,500	1,900	8,900
BaO	*(<*5*)	*558*	*56*	*5*	*112*	*80*	*200*	*70*
Rb_2O	*(<*10*)	*109*	*(<*10*)	*(<*10*)	*(<*10*)	*20*	*20*	*20*

I. Picrite basalt, King Isand.
II. Spiite (ophitic type), King Isand.
III. Spilite (basaltic type), King Island.
IV. Spilite (pillow lava), King Island.
V. Banded tuff, from between pillows, King Island.
(*a*) Olivine basalt, centre of dyke, Poortjie (Frankel, 1942 p. 18).
(*b*) Dolerite, Kokstad type, Execution Rock Sill (Walker and Poldervaart, 1949 p. 286).
(*c*) Average gabbro, according to Wager and Mitchell, 1943, p. 286.
Roman type—determined by chemical analyses.
Italics—determined spectrographically.
—not recorded.
*—present below sensitivity limit.

Hydrothermal Alteration

This particular section of the study of the petrology of these lavas is the most interesting, not only because it introduces an extremely interesting assemblage of minerals but because the origin of the solutions responsible for the changes is controversial.

Before proceeding to describe the types of alteration it would be advisable to define the term 'hydrothermal' as used by the author as nomenclature in this field is rather confusing and conflicting. In this paper the term is used in the same sense as used by Shand (1944) when he proposed that high temperature hydrothermal be the stage between 700°-300° C and low temperature hydrothermal below 300° C and the term to be all embracive in that it includes the effects of late magmatic alteration or alteration by extraneous solutions.

Hydrogrossular—a New Occurrence

Several occurrences of garnets associated with rocks of basic and ultrabasic intrusions have been recorded. Hutton (1943) pointed out that the mineral described as grossularite in the rodingites of New Zealand is not a true calcium garnet but one of the hydrogarnets belonging to the isomorphous series, tricalcium aluminate hexahydrate—grossularite. Yoder (1950), in his recent investigation on the stability of grossularite, suspects that the majority of naturally occurring garnets described as grossularite contain some hydroxyl groups. He is of the opinion that the dry end member of the grossularite—$Ca_3Al_2(OH)_{12}$ series does exist but that it cannot exist in the presence of water at elevated temperature.

Occurrence:—Hitherto a similar type of occurrence of hydrogrossular has not been described. As mentioned above, all examples have been from intrusive rocks. However, in 1910 Fenner described the occurrence of garnet as a secondary mineral in the Watchung basalt where it has been derived from olivine, felspar and diopside. Fenner writes 'This mineral has not heretofore been recognised under exactly similar circumstances, so far as the writer is aware'. This description appeared before the existence of a hydrogarnet series was established but no doubt if the garnets were studied in light of recent information it would prove to be a member of the grossularite—$Ca_3Al_2(OH)_{12}$ series.

In these basic volcanic rocks under consideration the hydrogrossular is definitely secondary. As previously mentioned it is found to be pseudomorphing almost perfect idiomorphic phenocrysts of olivine (see Plate VI, Fig. 3) and in some cases the plagioclase. It is also found in veins and vesicles (see Plate VI, Fig. 4). A great proportion of the glass in the breccias has been converted to hydrogarnet. Some pseudomorphs of chlorite after olivine show the presence of hydrogrossular along cracks and/or in a patchy fashion towards the centre. The hydrogarnet replacing the olivine and plagioclase is in the form of tiny granules and not one large crystal. In the vesicles and veins it has a concretionary form and the various members of the hydrogarnet series can be recognized by the differently coloured concentric layers and varying refractive indices. In some rocks the hydrothermal solution containing this mineral has attacked the groundmass, thus converting it into hydrogarnet, as illustrated in Fig. 4 on Plate VI. This hydrogarnet is more abundant in the picrite basalts than the spilites but in the latter some of the augite shows alteration around the edges to a brown coloured material. There is a possibility that this material may be one of the early phases during the garnetising process.

Properties:—The Hydrogrossular varies from dark brown to very pale brown or almost colourless.

The refractive index also varies from 1·663 to 1·753 according to the water content. It is interesting to note that in the vesicles the refractive index of the various layers increases from the edge inwards, commencing with a rather hydrous layer with low refractive index and grading into an almost anhydrous member of the series.

For the most part, the mineral is isotropic but some sections show very low birefringence.

Chemical Composition:—Owing to the nature of the mineral it was impossible to separate the various members of the series present so a chemical analysis was made on an average powder.

For comparison several other analyses have been tabulated in Table V.

TABLE V.—ANALYSES OF HYDROGROSSULAR

	I.	(a)	(b)	(c)	(d)
SiO_2	37·28	34·48	37·60	36·05	38 8
Al_2O_3	23 11	19·87	22 15	25 79	22 66
Fe_2O_3	5 26	0 61	·50	nil	1 75
FeO	0 73	0 85	·55	·56	
MgO	4 12	2 07	tr.	·15	·68
CaO	27 44	37 40	38·40	35·72	35 00
Na_2O		0·02	tr.	·13	
K_2O		0·01	tr.		
H_2O+	1 37	4·65	1 20	1 10	
H_2O-	0 44	0·23	·20		
TiO_2	0·06	0·03	·10	03	
MnO	n.dt.	·02	tr.	·15	30
Cr_2O_3	n dt.	n.dt.	10		
Total	99 81	100 24	100·95	99·68	99·19

I. Hydrogrossular, King Island, Tasmania, Anal. B. Scott.
(a) Hydrogrossular, Champion Ck , Waimea, New Zealand, Anal. F T. Seelye, (Hutton, 1943, p 74).
(b) Green "Jade", Buffelsfontein, Anal. H. G. Weall (Hall, 1924, p. 48).
(c) Grossularite, Roding River, Dun Mt., New Zealand, Anal. Dominion Lab. (Grange, 1927, p. 165).
(d) Green Grossularite, Dana's System of Mineralogy.

An interpretation of the analysis of the King Island hydrogarnet showing the amounts of the various garnet molecules is given below.

Andradite	16·81
Tricalcium aluminate hexahydrate	4·73
Grossular	53·22
Almandine	1·83
Pyrope	13·97
Silica	3·38
Corundum	4·91

The chemical composition based on the general formula $X_3Y_2(ZO_4)_{3}\text{-}m(OH)_4m$ (McConnell, 1942), of this particular hydrogarnet has been determined as $(CaMgFe'')_{2\cdot631}$ $(AlFe'''Ti)_{2\cdot063}$ $((Si,Al)O_4)_{2\cdot833}$ $(OH)_{\cdot667}$.

The valency of the formula was balanced by taking into consideration that $(OH)^{-1}$ replaces $(O)^{-2}$ of the SiO_4, leaving empty spaces.

In this case it was necessary to allot some alumina to the ZO_4 group where it occupied the empty spaces. Alderman (1935) pointed out that this was also necessary in his case when dealing with almandine garnets.

TABLE VI.—CALCULATION OF FORMULA OF HYDROGROSSULAR

Oxides	Weight %	Molecular Proportions	Ionic Ratios	Positive Ions
SiO_2	37 28	·621	·621	2·761
Al_2O_3	23 11	·226	·452	2·010
Fe_2O_3	5 26	·033	·066	·293
FeO	·73	·010	·010	·044
MgO	4·12	·103	·103	·458
CaO	27·44	·490	·490	2·179
H_2O+	1·37	·075	·150	·667
TiO_2	06	·001	·001	·004

Ca	2·179		Al	1·771		Si	2·761		OH	·667	
Mg	·458	2·681	Fe‴	·293	2 068	Al	·239	3·000	O	11·333	12·000
Fe″	·044		Ti	004							

Valency balance:

Excess positive		Deficit positive	
$\overset{-1}{(OH)}$ in place of $\overset{-2}{(O)}$	·677	$\overset{+3}{Al}$ in place of $\overset{+4}{Si}$	·239
$\overset{+4}{Ti}$ in trivalent group	004	Empty divalent spaces 2(3·000—2 681)	·638
Excess trivalent group	·068		
Total	·875		·877

According to Flint, McMurdie and Wells (1941) silica can replace water in both $3CaO,Al_2O_3,6H_2O$ and $3CaO,Fe_2O_3,6H_2O$ so that the end products become grossularite and andradite respectively. Chemically 6 molecules of H_2O are interchangeable with 3 molecules of SiO_2. The replacement, from a structural point of view, was explained by McConnell (1950) when in dealing with the crystal chemistry of montmorillonite, he likened the replacement of silica by water to the similar case of the hydrogarnets. He demonstrated that $(OH)_4$ has a stable configuration as discrete tetrahedra and 4H becomes equivalent electrostatically to Si in the structure.

X-Ray Data:—An X-ray powder photograph of the hydrogrossular was taken on a 9 cm. Unicam camera, using copper radiation and a nickel screen. X-ray data are given in Table VII.

Albite

Albite appears in these rocks as a complete replacement of a more basic plagioclase and in vesicles where it is associated with chlorite and has a pink colour in hand specimen.

Its refractive index is less than Canada Balsam and in the sections belonging to the zone normal to the 010 face the maximum extinction angle is 18½° indicating a composition of $Ab_{98}An_2$, almost pure albite. Sometimes the albite shows well defined lamellar twinning but at others it is untwinned. When untwinned in the vesicles it is difficult to distinguish it from quartz, the only means of distinction often being by the biaxial positive figure of albite as opposed to the uniaxial positive one of quartz. Often the albite shows secondary alteration to sericite, kaolin and chlorite.

TABLE VII.—INTERPLANAR SPACINGS OF HYDROGROSSULAR FROM KING ISLAND

h k l	d	Intensity	θ in degrees
110	7·195	*	6·151
220	4·303	*	10 321
222	3 572	*	12·462
400	3·026	****	14·761
420	2 689	****	16 600
332	2 563	**	17·504
422	2·460	***	18·265
431, 510	2·361	**	19·058
521	2 200	**	20·517
532	1·951	**	23·276
620	1·908	*	23 894
444	1·735	*	26 384
640	1 672	***	27·462
642	1·607	****	28 667
732, 651	1·539	*	30 062
800	1·503	**	30·855
840	1·344	**	34·994
842	1·313	**	35·945
664	1 283	*	36 944
864	1·116	**	43·667
10,4,2	1 110	**	44·603
880	1 063	*	46·506
10,71; 10,55	·978	**	52·055
12,60; 10,84	·897	*	59·302
14,40; 12,66	·826	*	68·958
14,42; 12,66 10,10,4	·818	*	70·386

****=very strong; ***=strong, **=weak; *=very weak

Strongest lines d=2·689, 1 607, 3·026.

Calculation of the size of the unit cell using the formula $a=\frac{\sqrt{h^2+k^2+l^2}\lambda}{2 \sin \theta}$ was determined to be 12·031A° when θ = 68·958° and 12·030A° when θ = 70·386°. The unit cell size of 12·03 for this hydrogarnet lies within the range 11·84A° for grossularite to 12 56A° for tricalcic aluminate hexahydrate given by Flint, McMurdie and Wells (1941).

As mentioned in the petrographical description of the rock types albite is found as an intergrowth and the ophitically arranged with fresh diopsidic augite. It may well be, under such circumstances, that the albite is primary and not secondary but this point will be discussed later. The fact remains that some. if not all, of the albite is definitely secondary.

Chlorite

Chlorite, perhaps, is the most common of the secondary minerals. It occurs in all the rocks, where it is found to replace or partly replace olivine, augite and plagioclase and to occupy vesicles and veins.

The chlorite varies from a colourless to rather dark green variety. Even in the same vesicle there has been known to be two different varieties. X-ray powder photography has shown that the chlorites do vary. The chlorite pseudomorphing olivine is generally of the colourless variety while that in the vesicles is of various shades of green. The most common variety is pennine.

The form of the chlorite pseudomorphing the olivine is in aggregates of fibro-lamellar structure. It has a low birefringence of ·003 and the interference colours range from black and grey to anomalous colours. The refractive indices are α = 1·591, γ = 1·594. The mineral is optically positive and is length slow. According to X-ray photography the three strongest interplanar spacings are d = 7·146, 3·558, 4·736. The green chlorite common in the vesicles is pleochroic. It, too, is optically positive and shows interference colours grading from grey to anomalous blue. Its refractive indices are higher than those of the colourless variety and are $\alpha = 1{\cdot}624$, $\gamma = 1{\cdot}629$. Most probably this chlorite is a variety of pennine too.

Epidote

Like chlorite, epidote is rather abundant and usually occurs as small granules or idiomorphic crystals in vesicles and veins, often lining the vesicles for chlorite. It is colourless to pale green and is slightly pleochroic. In some cases it shows twinning. It is distinguished from the diopsidic augite by its straight extinction.

Tremolite

Tremolite is very common in the series and occurs in all types of lava, aa, pahoehoe, and the massive type. It is almost colourless to very pale green with low birefringence and a maximum extinction angle of 20°. It replaces plagioclase in the block lava and commonly replaces or partly replaces augite in the massive lava towards the granite contact at Grassy. In some of the pahoehoe lavas it occurs in a peculiar intergrowth fashion with augite where it may be partially replacing that mineral or even replacing plagioclase. There is no evidence on which to decide. In the block lava it is also associated with chlorite in pseudomorphing the olivine and in the vesicles.

Prehnite

Prehnite occurs in the vesicles of some of the pahoehoe and pillow lavas. In hand specimens it is generally white with a greenish tinge. It is often in radiating form and shows typical bow-tie structure. It is length slow and has a double refraction of about ·02.

Sericite

This mineral is fairly common as a replacement of albite. However, it is found, too, sometimes lining the vesicles for prehnite or occurs as flakes with the prehnite.

The presence of sericite in the latter context was unexpected. At first this flaky mineral in the vesicles was considered to be either talc or pyrophyllite, which have similar optical properties to muscovite, as the assemblage of minerals was more in keeping with either of these, plus the fact that alumina and magnesia bearing solutions had been at work. However, after much difficulty a tiny fragment was separated from the prehnite and this was treated as a powder fragment because of its fine flaky nature and an X-ray photograph was taken. Photographs taken on small diameter cameras failed to distinguish the mineral from either talc or pyrophyllite but the photograph taken on a 19 cm. Unicam camera, when the lines were more spaced, definitely indicated that the mineral is sericite.

Calcite

One would expect to find more of this mineral than is actually present. It is found, however, in vesicles and veins. It is possible that the temperature conditions were too high for its formation in abundance.

Quartz

Quartz, like calcite, is not over abundant. It is only found in vesicles and veins and in the epidosites at Grassy.

Discussion

An examination of the chemical analyses and the mineral assemblage of the rocks indicate a great richness in alumina. The following questions arise. What is the origin of this constituent? Was it derived from a rich aluminous magma and the alteration the result of percolating late stage magmatic solutions, or was it derived from an external source and therefore the alteration the result of the invasion of the solidified lavas by foreign solutions?

The late magmatic stage alteration can be supported. The following equations indicate that the present mineral constituents could have been derived from a lava in which there has been a rearrangement of constituents, once the 'spilitic reaction' had commenced, that is assuming that the plagioclase was a more basic variety originally.

Each type of lava will be considered and the supposed original constituents will be taken into consideration.

Pahoehoe lava

(*a*) in which chlorite is the predominant secondary mineral

Olivine, Basic plagioclase, Pyroxene $\longrightarrow$ Chlorite, Hydrogrossular; Albite, Chlorite, Hydrogrossular; Pyroxene

1. $2CaAl_2Si_2O_8 + Na_2O + 2SiO_2 \longrightarrow 2NaAlSi_3O_8 + 2CaO + Al_2O_3$
   Anorthite $\longrightarrow$ Albite
2. $CaAl_2Si_2O_8 + 2CaO + SiO_2 \longrightarrow Ca_3Al_2(SiO_4)_3$
   Anorthite $\longrightarrow$ Grossular
3. $3Mg_2SiO_4 + 4H_2O + Al_2O_3 \longrightarrow Mg_5Al(OH)_8(Al,Si)_4O_{10} + MgO$
   Olivine $\longrightarrow$ Chlorite
4. $Mg_2SiO_4 + 3CaO + Al_2O_3 + 2SiO_2 \longrightarrow Ca_3Al_2(SiO_4)_3 + 2MgO$
   Olivine $\longrightarrow$ Grossular
5. $CaAl_2Si_2O_8 + 5MgO + 4H_2O + SiO_2 \longrightarrow Mg_5Al(OH)_8(Al,Si)_4O_{10} + CaO$
   Anorthite $\longrightarrow$ Chlorite

(*b*) in which prehnite is the predominant secondary mineral

Basic plagioclase, Pyroxene $\longrightarrow$ Albite, Chlorite, Grossular; Chlorite, Pyroxene; Prehnite, Quartz in vesicles

Equations 1, 2 and 5 as above.

$3CaO + Al_2O_3 + H_2O + 3SiO_2 \longrightarrow H_2Ca_2Al_2Si_3O_{12}$
Prehnite

Spilitic lavas (massive and pillow types)

Equations as for (*b*) except epidote formed more readily than prehnite.

$4CaO + 3Al_2O_3 + 6SiO_2 + H_2O \longrightarrow 2Ca_2Al_3(SiO_4)_3OH$
Clinozoisite

Aa lava

Olivine, Basic plagioclase, Pyroxene $\longrightarrow$ Chlorite, Hydrogrossular; Tremolite; Pyroxene

$3Mg_2SiO_4 + 4H_2O + Al_2O_3 \longrightarrow Mg_5Al(OH)_8(Al,Si)_4O_{10} + MgO$
Olivine $\longrightarrow$ Chlorite

$2CaAl_2Si_2O_8 + 3MgO + 4SiO_2 + H_2O \longrightarrow Ca_2(Mg,Al)_5(OH)_2(Si_4O_{11})_2 + Al_2O_3$
Anorthite $\longrightarrow$ Tremolite

$3CaO + Al_2O_3 + 3SiO_2 \longrightarrow Ca_3Al_2(SiO_4)_3$
Grossular

The late magmatic theory, however, appears to break down when it is realised that the tuffs, too, have been subjected to a similar alteration process. Even the glass fragments which had been completely solidified so that no late stage solutions could have remained have succumbed in places to hydrothermal alteration. A close study of the analyses of the volcanic glass and hydrogrossular may give a clue to this problem.

TABLE VIII.—ANALYSES OF VOLCANIC GLASS AND HYDROGROSSULAR

	Volcanic Glass	Hydrogrossular (Altered glass)	Constituents gained during alteration
SiO_2	44·11	37·28	
Al_2O_3	15·63	23·11	X
Fe_2O_3	5 45	5 26	
FeO	4 93	·73	
MgO	2·75	4·12	X
CaO	20 44	27·44	X
Na_2O	·80		
K_2O	·21		
H_2O	6·04	1·81	
TiO_2	·31	06	
MnO	·11	n.dt.	
Total	100·81	99·81	

Apparently this change involved an introduction of alumina, lime and magnesia. From this evidence it seems that the source of these constituents is external but where could this source be? In the introduction to this paper it was mentioned that the volcanic suite is intruded by granite at Grassy. This may be the answer to the question for not only do Nye and Knight (1943), in their report on the King Island scheelite mine at Grassy, report an introduction of alumina and lime in the interchanges of material during mineralization but the lavas apparently closer to the granite show a greater degree of hydrothermal alteration. Here the pyroxene of the lavas is practically wholly converted to tremolite. The plagioclase is albite and in some cases has been partially replaced by sericite, chlorite and hydrogarnet. Epidote and iron ore granules are abundant. Abundant veins and vesicles of pink albite and chlorite and sometimes quartz are very common and it is not unusual to find large patches of the lava converted to an epidosite, i.e., epidote, albite and quartz rock with abundant iron ore. The presence of tremolite would indicate that these lavas are not in the inner part of the contact aureole but in the outer, for according to Harker (1939) tremolite is not stable at high temperatures.

Further evidence to support the idea that constituents may have been gained from the granite is provided by the glacial tillite and varves. These rocks have been haematitized and dolomitized to a considerable extent. Sometimes the tillite is haematitized and the varves overlying it dolomitized. At other times most of the varves are haematitized as well and the dolomitization is not noticed. This is possibly due to the magnesia being lost to the overlying lavas and being incorporated in the formation of new minerals such as tremolite and chlorite. Unfortunately it has not been possible to trace the iron and magnesia rich zones consistently in the lavas because of the faulting which postdated the granite. Field evidence is consistent with the idea that a magnesia front is preceding an iron front. There is ample evidence of magnesia having been gained by the lavas but iron is not over abundant as evidenced by the formation of tremolite rather than actinolite and the almost colourless variety of chlorite. However, some perfect cubic crystals of iron pyrities are sometimes present in the lavas but these are often quite abundant in the dolomitized varves.

The temperature at which this hydrothermal alteration was achieved must be considered. The presence of such a hydrogarnet, containing a small amount of water, indicates that fairly high temperature hydrothermal conditions prevailed.

Yoder (1950), as a result of preliminary experimental work, tentatively states that members of the hydrogrossular series form in the presence of water at a temperature under approximately 750° C at atmospheric pressure and above 300° C, below which, according to field data, a different mineral assemblage, viz., calcite, quartz and zoisite, would be stable. Fenner (1910) states that in the Watchung basalt when the alteration was delayed until a rather late stage, the nodules of absorbed olivine passed over into chlorite, but in an earlier period, while the temperature was high, garnet was the chief mineral formed. He also points out that with an increase in prehnite, a mineral requiring a lower temperature for formation, in the rocks there is a decrease in garnet. This, too, has been noted in the King Island lavas as mentioned before. Apparently as the temperature fell below the range in which hydrogrossular was stable the excess lime and alumina were absorbed in the formation of prehnite, epidote, and other low temperature hydrothermal lime bearing minerals. The absence of zeolities and the relatively small amount of calcite and quartz for such an altered series are also indicative that the temperature conditions were higher than usual. In support of the late magmatic stage of alteration there is an apparent correlation of the amount of garnet with the degree of crystallization and hence fall in temperature. The fine grained porphyritic rocks such as the aa or fine grained phase of the pahoehoe lavas, which no doubt cooled rather rapidly, contain more hydrogarnet than the coarser grained pahoehoe and spilitic types which contain abundant prehnite.

The general conclusion to be drawn from the hydrothermal study is that if one considers all or some of the albite to be secondary, then both late magmatic reactions and reactions with solutions from external sources have played a part, the former as indicated by the spilitic reaction and the latter by the introduction of alumina. Lime and magnesia, which also play big parts, could have been derived from outside or from the magma itself during the late stage reactions. However, if one considers all the albite to be primary, then most of the alteration is post magmatic and probably due to the granite intrusion.

THE PROBLEM OF THE PYROXENE AND ITS BEARING ON THE ORIGIN OF THE ALBITE

An interesting feature of these lavas is the freshness of the pyroxene when the felspar has been albitized. Usually in spilitic rocks the ferromagnesian minerals are changed to chlorite and epidote but apparently not in this case.

Benson (1915) describes spilitic rocks, in which the augite is unusually fresh, from the Nundle District, New South Wales. He concludes that the albite may be primary in those particular rocks. In the King Island series under consideration there is further strong evidence to support the theory that the albite, or at least some of it, is primary because of its intergrowth and ophitic relation with the augite. The presence of ophitic fabric does indicate on the one hand that the albite may be primary, or on the other hand that it may be secondary, the result of sodic metasomation of normal basaltic rocks as indicated by Turner (1948) when discussing albite associated ophitically with fresh augite from rocks described by Benson from New South Wales and also by Eskola (1925) from Kendjarvi, Finland. However, in this suite the author feels that she can afford to be more assured and state that at least some of the albite is primary because of the eutectic between it and the diopsidic augite. The diagram by Bowen (1928) showing the crystallization of mixtures in the plagioclase field of the system albite-anorthite-diopside indicates that a eutectic does exist between diopside and albite, given the requisite conditions for formation. Although Bowen was concerned with an anhydrous melt and the melt from which this rock was derived was no doubt hydrous it is unlikely that the relationship between albite and diopside would be appreciably affected.

It may happen that some of the albite is primary and crystallized out at an early stage and some late magmatic. Given the suitable conditions of composition of a sodic magma and the right temperature it is possible for the albite to be primary as shown by the eutectic. On the other hand, if temperature conditions are not suitable the magma may crystallize in the same fashion as a normal basaltic magma, leaving at the end a highly sodic fraction which would react with the more basic plagioclase, such as labradorite, to form albite.

Further confusion is added by the presence of beautifully fresh volcanic glass which seems to be too deficient in soda to indicate an original sodic magma from which primary albite could crystallize in spite of its position on Fig. 2, which indicates spilitic affinities.

Resistance of the pyroxene to alteration may be due to the fact that it was already in equilibrium with the surrounding mineral assemblage. Its optical properties determine it to be a diopsidic variety, therefore rich in lime and magnesia and possibly immune to further change by an infiltration of these constituents.

A Note on the Formations of the Lavas in the Field

Brief descriptions of the modes of occurrence of the volcanic series have been given earlier in the paper. The modes of occurrence, with the exception of the pillow lavas, suggest emission under subaerial conditions, the aa and pahoehoe forms and the columnar structure in one of the massive flows being the strong supporting factors.

No definite boundaries can be drawn between the pahoehoe, pillow and aa lavas as there are to be seen transitions from one to the other. In places the lavas are definitely of the pahoehoe, pillow or aa form but in others the pahoehoe seems to merge into the pillow and the aa lava appears to have formed by the breaking up, as it were, of the pillow and pahoehoe lavas. Sometimes the pillow-like structure has taken on a long twisted snake-like appearance about 18 inches in diameter, still with the cavity in the centre. The pahoehoe form appears at times to curl round and resemble the pillow form. Isolated pillows amongst block lava have a fractured appearance indicating that the blocks may possibly have been derived from pillows. This is illustrated by Fig. 1 on Plate II. These pillows often show excellent examples of bulbous budding. Noe Nygaard (1940) refers to floating basalt globes (30-60 cms. in diameter) amongst breccia which are now broken and occur as sector-like fragments or segments but these are the result of a stage during the subglacial intrusion of a magma.

The massive lava flows, on the other hand, are independent and are separated by beds of volcanic tuff and breccia. Breccia tuff and block lava appear between the pillows or interbedded with them. The so-called block lava in this case may be more in the nature of volcanic bombs. At times some of the pahoehoe forms seem to curl around small patches of breccia.

According to Washington (1923) aa and pahoehoe are the chief and most commonly occurring types of basaltic lavas and chemically there is no general difference in the composition of the two forms of lava. Both occur side by side and in the same flow in the Hawaiian Islands. Unfortunately, a chemical analysis of a pahoehoe lava was not attempted because of its amydaloidal nature and the zonal arrangement of crystallization. It would have been interesting to have seen the relationship between FeO and Fe_2O_3 for according to Washington the proportion of FeO to Fe_2O_3 is uniformly higher in the pahoehoe form than in the aa.

The aa form is supposed to be uniformly more crystalline than the pahoehoe which is highly vitreous. However, in the King Island rocks the reverse is the case. The aa lava has given rise to a very fine grained rock, some of which was probably glassy, containing phenocrysts which were originally olivine. Vesicles are wanting. The rock resulting from the pahoehoe lava, on the other hand, is very crystalline, the degree of crystallinity increasing from the surface towards the centre. The pahoehoe rock, mineralogically, seems to bridge the gap between the picrite basalt (aa lava) and the spilite (pillow lava). The pillow lavas sometimes resembles more the picrite basalt, especially when it is found amongst the block lava, and at other times seems to represent the finely crystalline pahoehoe rock. From observation in the field the author is inclined to think that the pillow lavas, generally, are varieties of the pahoehoe lavas and have formed under slightly different conditions of cooling. Possibly the pahoehoe lava has flowed into a local body of fairly shallow water thus facilitating a more rapid cooling and chilling process resulting in the formation of the pillows. As the pillows accumulated to the depths of the water the lava took on again the pahoehoe form.

According to Washington (1923) Day and Shepherd regard the pahoehoe lava as the high temperature form containing much gas and cooling quickly throughout because of the rapid expansion and elimination of the gas.

Although the vulcanicity was closely associated with glacial conditions the extrusions were probably not of the subglacial type as described by Noe Nygaard in 1940, these subaerial lavas having been emitted during an ice recession. There is evidence to show that volcanic action commenced before glaciation ceased in that flows of lava are found interbedded with varves. Also in other places the lavas are irregularly mixed up with the varves, suggesting that the lava was emitted through unconsolidated sediments.

The presence of glass fragments in the breccia towards the base of the volcanic series is again suggestive of conditions suitable for rapid chilling of the magma. Most probably the molten fragments were hurled into the melting ice, thus becoming rapidly solidified to glass.

Above it was suggested that the pahoehoe lava may have flowed into local bodies of water to form the pillow structures. These local bodies of water may have been melted ice water. Association with the pillows are breccias also containing glass, now devitrified or altered for the most part.

Evidence that the centre of eruption was close at hand is provided by the presence of a bed, about 2 feet thick, of 'shower droplet' rock. This rock is described earlier in the paper and as mentioned it is probably the result of the accumulation of small lapilli of lava which have dropped one on top of the other when almost, though not completely, solidified.

Throughout the period of vulcanicity the outpourings of lava were interrupted at intermittent periods when the type of action became explosive and showers of ash and other fragmental material were ejected.

SUMMARY

The volcanic rocks from south-east King Island provide yet another interesting occurrence of a spilitic suite in which the pyroxene is unusually fresh. This time the magma has solidified in the forms of massive, pahoehoe, aa and pillow lavas together with subsidiary amounts of fragmental rocks.

The most important points to be drawn from the study are as follows:—

1. Chemically the rocks may be grouped into spilites and picrite basalts.

2. The lavas themselves provide evidence in the form of ophitic fabric and intergrowth between albite and diopsidic augite that some at least of the albite is primary. However, it is possible for some of the albite to have been formed at a late magmatic stage from soda rich solutions remaining after the normal crystallization of a soda rich basaltic magma.
3. The fragmental rocks provide much confusion in revealing fragments of beautifully fresh glass which is poor in alkalies but very rich in lime. Nevertheless, it shows spilitic affinities when plotted on the triangular diagram, Na_2O, FeO, MgO of Sundius (1930).
4. This volcanic glass when altered appears to have gone mostly and quite readily to hydrogrossular, a fact which is not surprising when the chemical composition of both are compared.
5. Hydrothermal alteration is prevalent and has most probably been due to both late magmatic and post magmatic solutions, the latter being derived from a nearby granite intrusion.
6. The alteration has enriched the rocks in alumina, lime and magnesia and has produced an interesting assemblage of minerals—hydrogrossular (a new occurrence), albite, chlorite, epidote, prehnite, tremolite, calcite and quartz—indicating fairly high temperature hydrothermal conditions at the time of their formation.
7. The pyroxene, diopsidic augite, is unusually fresh and it has been suggested that it was probably in equilibrium with the surrounding mineral assemblage and therefore immune to further change by an infiltration of lime and magnesia in which it was already enriched.
8. The modes of occurrence of the volcanic rocks indicate that vulcanicity commenced before glacial action has ceased. The emission was subaerial and took place, for the most part, during a recession of the ice.
9. The formation of the breccia containing the glass is possibly due to the chilling action of melted ice water.
10. Transitions from pahoehoe to pillow and aa lavas and vice versa exist and the formation of pillow lavas may be the result of the pahoehoe lava flowing into local bodies of this water.

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Locality Index

Locality	Quadrangle	Latitude S	Longitude E
Barrier Creek		39°58′	144°08′
City of Melbourne Bay	S E King Is. 10	40°00′	144°03′
Conglomerate Creek		39°54′	144°08′
Dundas	Zeehan 50	41°53′	145°28′
Fraser River	Sea Elephant 6	39°54′	144°02′
Grassy	S. E King Is. 10	40°03′	144°04′
Grassy River	S E. King Is. 10	40°03′	144°04′
King Island		39°35′—40°16′	143°50′—145°17′
Montana	Zeehan 50	41°51′	145°17′
Nundle		31°27′	151°08′
Yarra Creek	S.E. King Is. 10	40°00′	144°03′
Zeehan	Zeehan 50	41°53′	145°21′

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DESCRIPTION OF PLATES

PLATE I.

FIG. 1.—A field of pillow lavas just south of City of Melbourne Bay

FIG. 2.—Pillows of lava separated by banded tuff.

FIG. 3.—A pillow of lava showing the differential weathering of the central and marginal areas Note how the varioles stand out like marbles

FIG. 4.—Central portion of a pillow of lava showing even weathering, the varioles being distinguished by their lighter colour.

PLATE II.

FIG 1.—A pillow of lava, showing bulbous budding, amongst the block lava illustrated in FIG 2 Note the irreguar cracking of the pillow.

FIG. 2.—A field of block lava south of Barrier Creek

FIG 3.—A general view of the thin flows of pahoehoe lava showing the general dip of the volcanics

FIG 4.—A near view of an individual pahoehoe lava flow Note the variolitic structure towards the centre.

PLATE III.

FIG 1.—Weathered surface of the "shower droplet" rock showing the size and shape of the lapilli.

FIG. 2.—Unweathered surface of the same specimen. Note that some of the lapilli are welded together.

FIG. 3.—A specimen of portion of the surface of a pahoehoe lava flow showing ropy structure

FIG 4.—A specimen of breccia containing fragments of volcanic glass showing alteration to hydrogrossular indicated by the white bands The white patches also indicate hydrogrossular replacement.

PLATE IV.

FIG. 1.—Picrite basalt similar to the specimen analyzed Olivine phenocrysts are pseudomorphed by almost colourless chlorite which is pierced by needles of tremolite The groundmass is cryptocrystalline and consists of pyroxene and tremolite. ×56.

FIG 2.—Pahaehoe lava containing radiating augite and laths of albite which are partly replaced by chlorite and hydrogrossular Albite is the material in the vesicles. ×56.

FIG 3.—Spilite (basaltic type) showing laths of albite and intergranular augite. ×56

FIG. 4.—Spilite (pillow lava type) showing radiating augite and albite with granules of magnetite between the tiny sheafs. Analysed specimen. ×56

PLATE V.

FIG. 1.—Spilite (analyzed specimen) showing graphic intergrowth (eutectic) between diopsidic augite and albite which has been greatly replaced by sericite. The albite is at extinction. ×56

FIG. 2.—Spilite showing intergrowth as above. The intergrowth has not developed in any definite crystallographic direction ×56.

FIG. 3.—Spilite (ophitic type) showing albite laths penetrating diopsidic augite. Albite has been greatly replaced by sericite and is at extinction in this figure Analysed specimen. ×56.

PLATE VI.

FIG. 1.—Volcanic breccia showing glass fragments replaced by chlorite and hydrogrossular towards the margins. ×56.

FIG 2.—A large fragment of volcanic glass in breccia showing alteration to hydrogrossular, represented by the dark bands. ×56.

FIG. 3.—Portion of the chilled margin of a pahoehoe lava showing the occurrence of hydrogrossular (small dark spots) in vesicles associated with chlorite and pseudomorphing olivine ×35.

FIG. 4.—Picrite basalt showing the occurrence of hydrogrossular in a large vescile and as a replacement of olivine and the groundmass where it is indicated by the dark patches. ×35.

The photomicrographs (FIGS. 3 and 4) were taken in the Department of Mineralogy and Petrology, University of Cambridge.

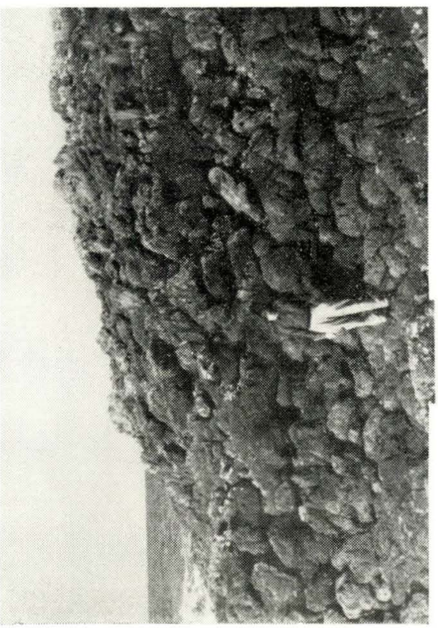


Figure 1

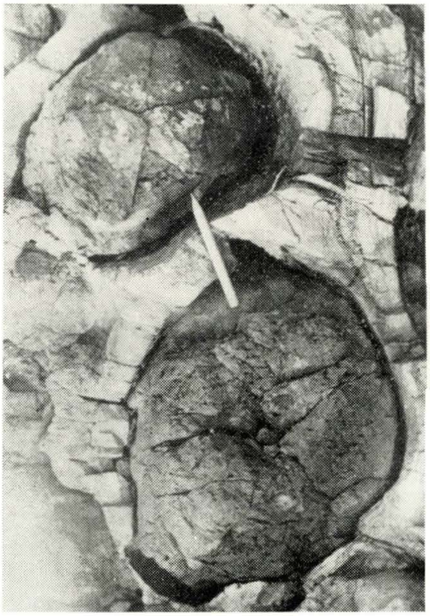


Figure 2

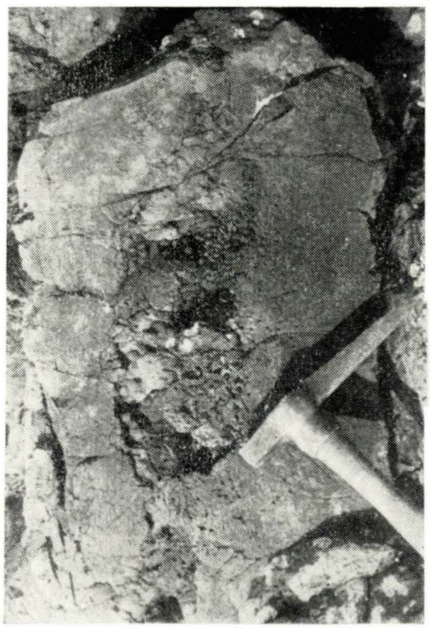


Figure 3

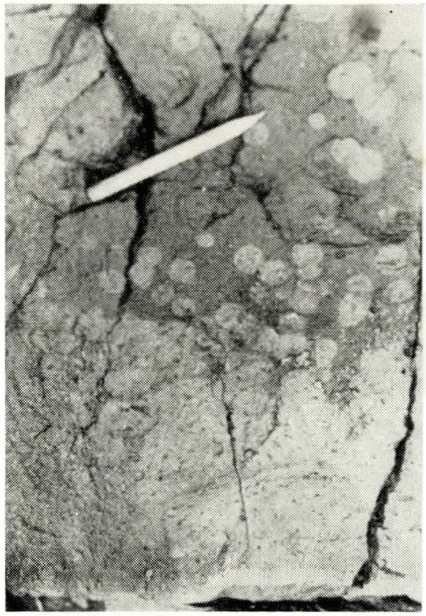


Figure 4

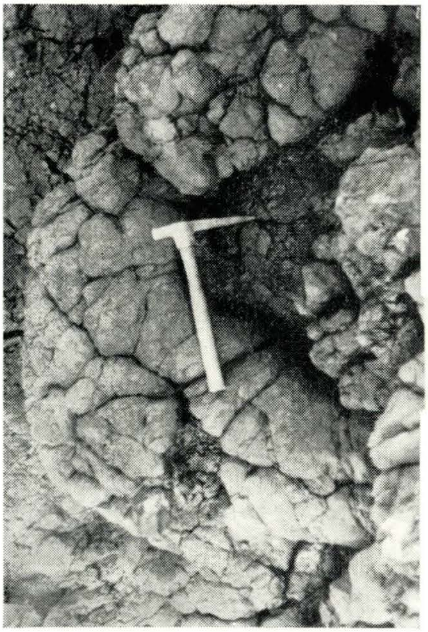


Figure 1

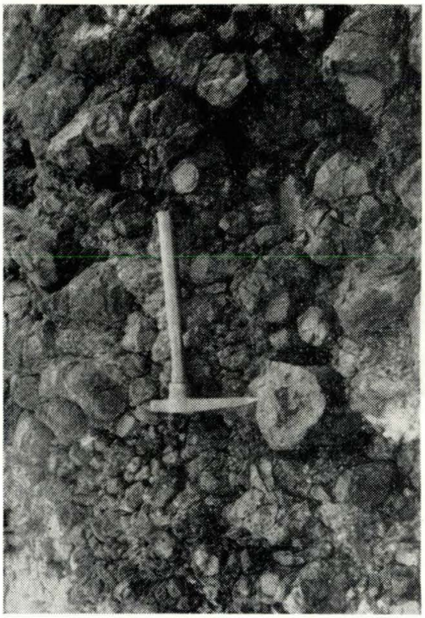
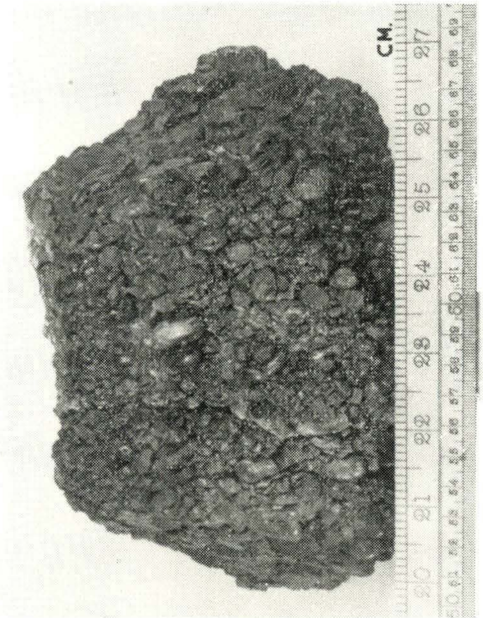


Figure 2

Figure 3

Figure 4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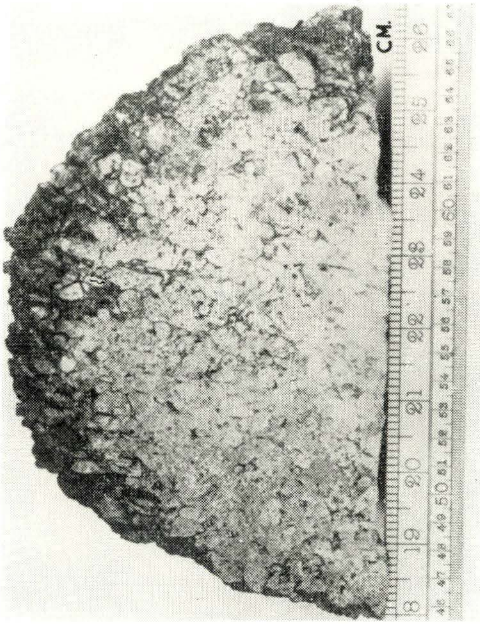
Figure 2

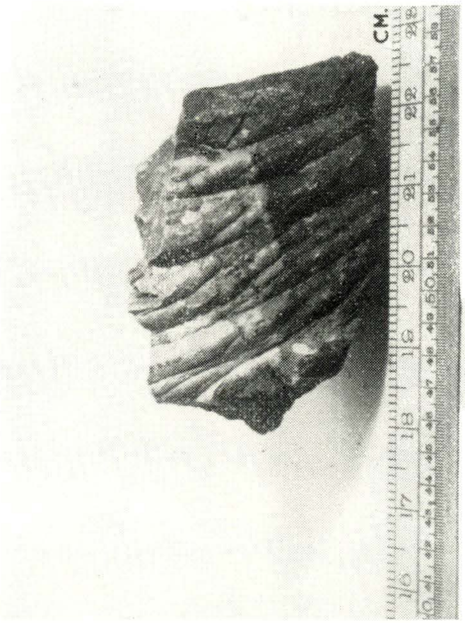
Figure 3

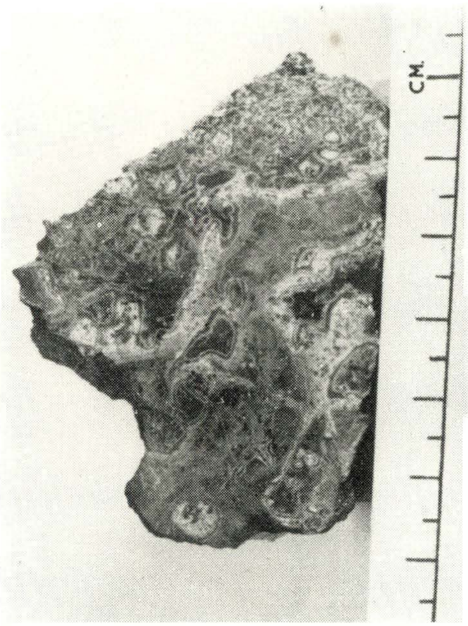
Figure 4

Figure 2 x 56

Figure 4 x 56

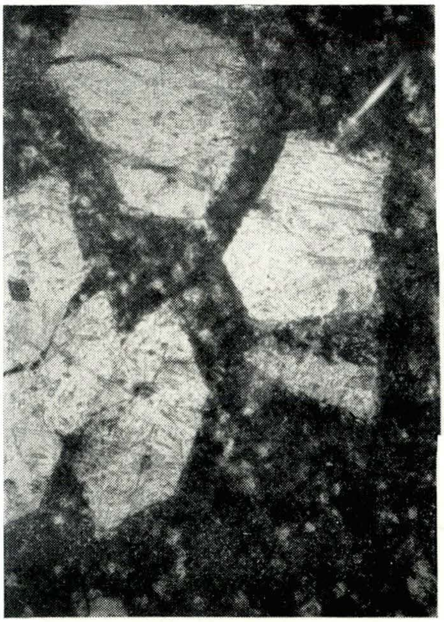

Figure 1 x 56

Figure 3 x 56

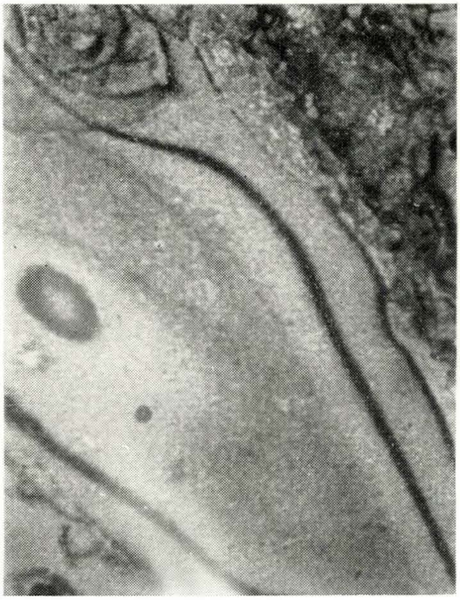

Figure 2 x 56

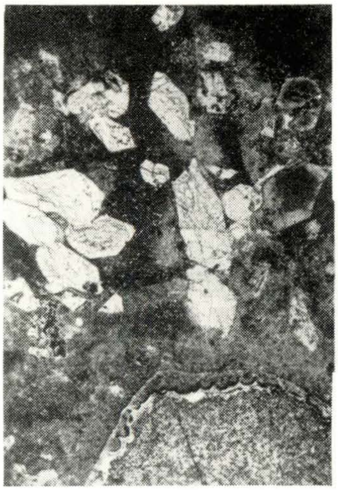

Figure 4 x 35

Figure 1 x 56

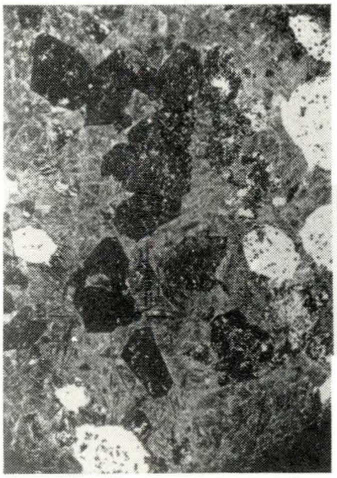

Figure 3 x 35

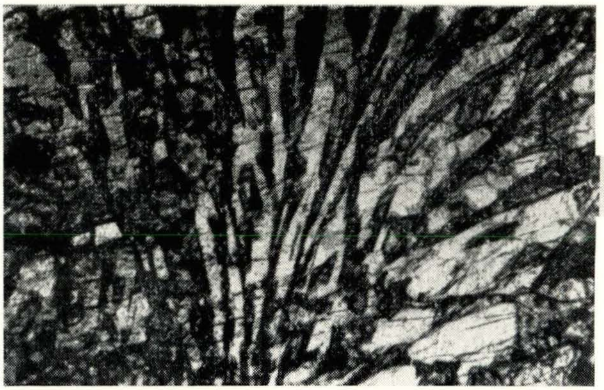

Figure 1
x56

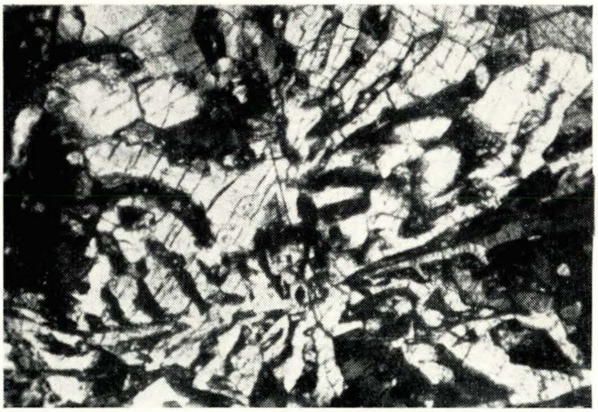

Figure 2
x56

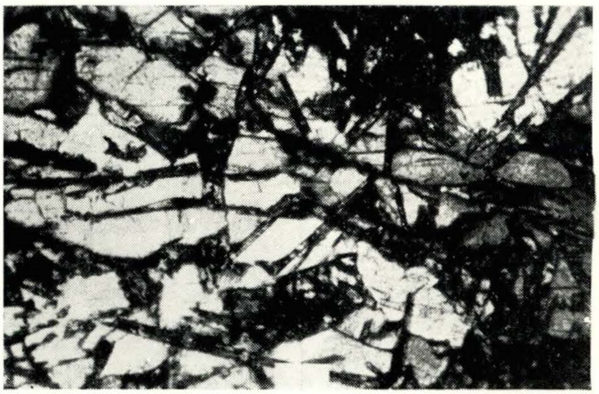

Figure 3
x56

A Note on the Occurrence of Intergrowth between Diopsidic Augite and Albite and of Hydrogrossular from King Island, Tasmania

BY

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Copy of the manuscript of the paper

REVISED INTERPRETATION OF THE GEOLOGY OF THE SMITHTON DISTRICT OF TASMANIA.

By

S. WARREN CAREY AND BERYL SCOTT.

which will appear in the Papers and Proceedings of the Royal Society of Tasmania for 1952.

REVISED INTERPRETATION OF THE GEOLOGY OF THE SMITHTON DISTRICT OF TASMANIA.

by

S. Warren Carey and Beryl Scott.

with 2 Plates and 1 Text Figure.

Abstract:

The geology of the Smithton district is described in Bulletin No. 41 of the Geological Survey of Tasmania. The abundance of vesicles and amygdules mentioned in the description of the doleritic rocks which form a prominent feature of the area, seemed inconsistent with their interpretation as intrusive dykes and prompted us to check their occurrence in the field. We report that these rocks do in fact contain abundant vesicles and amygdules, and that in places they exhibit pillow structure and are associated with volcanic breccias and volcanic bombs. We have examined the exposures on which an intrusive character was claimed and are satisfied that they are due to extrusive and volcanic phenomena similar to those we have studied in the Cambrian or Late Proterozoic volcanic suite on King Island, 80 miles to the northwest. Native Copper which is described as a common constituent, we find to be not native copper but pyrrhotite. "Fine-grained silicified conglomerate interbedded with dense black cherts exposed in the Irishtown gravel pits" (loc. cit. p.31), we find to be silicified oolite. The two formations of dolomite described in the bulletin we consider to be a single formation repeated by strike faulting.

We agree with the previous authors in their correlation of their "Slate Stage" with the Dundas Group.

We also correlate this group with similar rocks outcropping on the east coast of King Island and suggest that the tillite found in close association with these rocks in several parts of the State is part of the Dundas Group and is of Middle Cambrian age. We suggest that a silicified breccia described by the previous authors is possibly the representative of the tillite in the Smithton district.

Introduction.

The geology of the Smithton district of northwest Tasmania has been described in detail by Nye, Finucane, and Blake, in Bulletin No. 41 of the Geological Survey of Tasmania. A prominent feature of the geology of the district as described by the authors is a broad but rather complex dolerite dyke having a general meridional trend which the authors suggest to be of Devonian age and intrusive into the Dundas Slates and Breccias of Cambro-Ordovician (now known to be Middle Cambrian) age. Their descriptions of these rocks make frequent reference to the presence of amygdules. For example:-

> p.66. "The white amygdules consist mainly of aggregates of quartz and calcite which may contain augite or chlorite. The green amygdules consist of a central nucleus of quartz, surrounded by fibres of the same material, with a thin outer layer of chlorite; the fibrous quartz between the nucleus and the outer chlorite layer radiates in fan-shaped fashion from a number of points on the inside of the chlorite layer. In a small outcrop of the dolerite on the northern spur of Tier Hill the white amygdaloidal inclusions are so numerous that the rock has quite a coarse appearance".
>
> p.68. "There are two main types ....both are amygdaloidal".
>
> p.69. "The amygdules consist of quartz and

> chlorite; in some cases the chlorite occupies the centre of the amygdule, and is surrounded by quartz; in others the amygdule is of quartz surrounded by a thin film of chlorite".
>
> p.69. "The amygdules are small vesicular cavities lined with quartz".

These descriptions of abundant amygdules seemed to us inconsistent with the view expressed by the authors that these rocks were intrusive. In addition one of us (B.S.) has been studying the Cambrian or Late Proterozoic basic lavas of Tasmania generally, and has found them to be widely distributed in the area between Queenstown and King Island, and this suggested that the amygdaloidal basic rocks at Smithton associated with the Cambrian Dundas Group might in fact be another occurrence of these old lavas.

<u>Extrusive Character of so-called Dolerite.</u>

We examined the "dolerite dyke" in the following localities: Tier Hill, Coward's Road, the quarry ¾ mile south of Groom's Road on the Smithton-Trowutta Road, along the eastern shore of Duck Bay, and for a distance of about ¾ mile eastwards from Park Point along the shore. In each of these localities there was strong evidence to support an extrusive rather than an intrusive origin.

Throughout this paper the term "dolerite dyke", as used by Nye, Finucane and Blake, will be replaced by "basic volcanics".

The basic volcanic rocks occupy a similar stratigraphical position in the Dundas Group to those which crop out along the southeast coast of King Island and at Zeehan. For the most part they overlie well bedded chocolate coloured shales, but, as on King Island, volcanic activity commenced before deposition of the shales was completed.

About 30 to 35 chains east of Park Point occurs a bed of volcanic breccia, fragments of which range from about ¼ inch to 1 inch in diameter with a few up to 3 inches. The fragments are generally angular and are composed of very fine grained greenish-grey volcanic rock, cemented together by dark chocolate-coloured shaley material. (See Plate I, Fig. I). It seems that showers of volcanic material fell on to the unconsolidated mud which probably oozed up between the fragments of lava. The description on pp.70-71 (loc. cit.) of a thin section of the altered basic augite porphyrite which was assumed to occur in dykes and tongues on the eastern margin of the dolerite dyke could be applied to thin sections of the fragments of rock in the breccia, examined by us. It seems to be no more than a quickly cooled phase of the main rock type. The similarity between the main doleritic rock type and the basic augite porphyrite is also borne out by the chemical analyses given in the bulletin.

Closely associated with the breccia are volcanic bombs which fell on unconsolidated mud. These bombs are not nearly so numerous as the fragments of the breccia. They vary from about 2 inches to 12 inches in diameter, the most common size being about 4 inches. The exceptional number of vesicles which in places gives the rock an appearance of pumice, indicates quick cooling, and on examination of a thin section the state of incipient crystallization of the rock also confirms the condition of cooling. Needles of plagioclase appear to be embedded in a groundmass of devitrifying glass. Numerous microscopical vesicles filled with quartz and chlorite are also present. An illustration of a bomb appears on Plate I, Fig. 2. Some of the bombs have re-entrant and irregular shapes on cross sections exposed by weathering, but it appears that the bomb when it fell into the mud was still hot enough to be plastic under its own weight, with the result that bulging deformation or viscous protrusion occurred leading to concave and (in section) re-entrant profiles.

The association of the breccias and volcanic bombs with the slates was given an entirely different interpretation by Nye, Finucane and Blake on pp.72-73; "the slate appeared to be undergoing digestion by the dolerite, the process resembling magmatic stoping on a minute scale".

Overlying the fragmental rocks is a dense massive fine grained greyish-green lava in the same relative stratigraphical position as the massive lavas of King Island. Petrographically the rock resembles those on King Island and their correlates elsewhere in Tasmania. Microscopic descriptions appear in the bulletin on pp.65-66. One slide of a porphyritic rock appears to contain phenocrysts of olivine which have been completely pseudomorphed by chalcedony and bright green nickel bearing chlorite. None of the original mineral remains but the crystal outlines and the fact that the pyroxene in the slide is fresh indicate olivine. On p.69 the presence of biotite is mentioned. "Chlorite and biotite occur as interstitial grains; the latter is not common". In all the sections of rocks examined not a trace of biotite has been found, but hydrogrossular, a brown coloured mineral in ordinary light, has been noted and when present is usually associated with chlorite as interstitial grains and in vesicles or replacing tiny crystals of olivine. It is possible that this mineral, a member of the hydrogarnet series, has been mistaken for biotite. The occurrence of hydrogarnet in the King Island lavas has been described recently by one of us (Scott, 1951.). Whenever possible the plagioclase was studied carefully. It was on all occasions found to be albite and to show the characteristic clear appearance under high power. In some sections it showed alteration to chlorite and very rarely to epidote. In parts this massive lava is quite amygdaloidal or vesicular, this phenomenon being most noticeable in the rocks outcropping on Tier Hill and in the quarry along the Smithton-Trowutta Road. The vesicles may be oval or irregularly shaped and vary from microscopical dimensions to about ⅜ inch in diameter. The infillings are generally quartz, albite, calcite, chlorite and epidote. We can account for the augite recorded from the vesicles by the previous authors (p.66) only by assuming that some of the epidote was identified as augite.

The next rock type in the suite appears to be the pillow lava which is found along the eastern shore of Duck Bay. The pillows (see Plate I, Fig. 3, & Text-Fig.) range from 1 foot to 6 feet in diameter, and were immediately recognised because of their similarity to

INSERT TEXT FIGURE ABOUT HERE.

those on King Island, notwithstanding the fact that the

Smithton pillows are more broken up by mechanical weathering. Between the pillows is to be found banded tuff, the misinterpretation of which may have contributed to the theory of an intrusive origin. Microscopically the rock type closely agrees with the description of the mugearites given on pp.68-70 and it seems possible that the so-called tongues and dykes of mugearites have been confused with the pillow lavas. The pillow lava consists of laths of plagioclase approximately 0.5 mm. long with interstitial chlorite, magnetite and possibly ilmenite, and tiny needles of apatite. The plagioclase shows quite good albite twinning, and has an extinction angle of 17^{o} and a refractive index less than Canada balsam indicating albite with the composition $Ab_{95}An_{5}$. The chlorite is greenish-brown in colour and has probably been derived from the pyroxene, no fresh grains of which still remain. From the mineralogical and chemical compositions this rock type would better fit the name of spilite, although the CaO and MgO contents are rather lower and the Al_2O_3 content rather higher than usual for spilites.

Several chemical analyses have been given in the bulletin and on the basis of these and the microscopical descriptions the rocks were divided into fine grained and porphyritic varieties of dolerite, mugearites, and augite porphyrites. However, with the experience of one of us (B.S.) in studying similar ancient volcanics elsewhere in Tasmania it seems that such a classification is unnecessary. Generally speaking there is not a great deal of variation in the rocks either mineralogically or chemically. The slight variation chemically may be accounted for by the slight difference mineralogically and by various stages of hydrothermal alteration, the vagrant constituents usually being Al_2O_3, CaO, MgO and Na_2O.

To summarise, the evidence on which we base our belief that the igneous rocks are extrusive rather than intrusive is :

(i) Great abundance of vesicles and amygdules.

(ii) Presence of pillows, volcanic bombs and breccia.

(iii) General homogeneous fine grain-size inconsistent with the great volume and thickness of basic rock regarded as an intrusion.

(iv) The similarity in broad characters and in details to known basic lavas occurring in the same stratigraphic group, with a distribution which straddles the Smithton occurrences.

That small dykes associated with the volcanic rocks exist is not denied. The rock material in them is essentially the same as the volcanic type. Such cognate dykes are a common feature of the King Island volcanic suite.

Re-determination of so-called Native Copper.

Scattered rather abundantly through the basic volcanic rocks are specks and flakes of a copper coloured mineral referred to in the bulletin as native copper. A similar looking mineral has been found in much less abundance in the King Island basic volcanic rocks associated with a dark green chlorite (the nickel bearing variety garnierite). This was thought to be niccolite which megascopically resembles native copper (Scott 1951). The so-called native copper of the Smithton rocks is also associated with nickel bearing chlorite. However, chemical and magnetic tests by one of our students (R.J.Ford) have now established that the mineral is pyrrhotite, probably containing some nickel. No chemical reaction for copper even in small quantity could be obtained. It is probable that the King Island mineral is actually nickel bearing pyrrhotite also. It is of interest to record that we observed the same nickel bearing chlorite associated with the basic lavas at Heathcote, Victoria, which are recognized as correlates of the Dundas Group, to which the Smithton lavas are also referred.

Possible Occurrence of Tillite.

The previous authors have described a silicified breccia which outcrops as a small rocky headland about 10 chains west of the mouth of Deep Creek. Stratigraphically it is at or near the base of the Dundas Group. In its general appearance it closely resembles some phases of the tillite at King Island and at Zeehan. However, pebbles and matrix are completely silicified and there is no possibility of extracting striated pebbles to confirm the glacial origin. Its position with respect to the basic lavas is analogous to the position of the tillite at King Island and Zeehan. Complete metasomatic replacement is a common phenomenom in the tillite elsewhere. At King Island some outcrops are dolomitised, both the pebbles and the matrix being wholly replaced by dolomite. Elsewhere the replacement is by haematite. We suggest that this Smithton breccia may be tentatively correlated with the tillite though it should be emphasized that a glacial origin cannot be established on the evidence available in the Smithton district alone.

Re-determination of Silicified Conglomerate as Silicified Oolite.

On page 31 of the bulletin the previous authors described a silicified conglomerate in their "Chert Sub-stage" in the following terms: "In the Irishtown road gravel pits, about a mile south of Smoker's Bank road, a fine-grained silicified conglomerate is interbedded with dense black cherts and grey and purplish-grey slates. The rock is composed of rounded, with some angular, quartzose pebbles, set in a siliceous matrix. The pebbles are black or white in colour, and remarkably uniform in size; their diameter is one-eighth to three-sixteenths of an inch. The rock sometimes has the appearance of a silicified grit, but, as the bulk of the pebbles are rounded, it corresponds more to a fine-grained conglomerate. Grey and purplish-grey slates are interbedded with the above members."

We had no difficulty in identifying the locality and found the rocks answering closely to the description of the so-called silicified conglomerate. However, we find the rocks to be not a silicified conglomerate but a silicified oolite. (See Plate I, Fig. 4). Microscopically the silicified oolite indicates complete replacement of the original carbonate by quartz. Definition of the individual oolites is less distinct than in hand specimen where colour plays an important role. Both the oolites and the material between them consist of finely granular quartz. The quartz grains in the oolites are a little larger and in some cases towards the centre may grade to 0.5 mm. Macroscopically, the rock is sometimes deeply pitted, presumably owing to removal in solution of unsilicified carbonates.

<u>Relation of "Chert Sub-stage" to Dolomite "Sub-stage".</u>

The previous authors suggested (p.30) that their Dolomite Sub-stage is intimately associated with the Chert Sub-stage, and that it underlies or forms the base of the

Chert Sub-stage. We go somewhat further and suggest that the "Chert Sub-stage" of the previous authors has no separate existence as an independent formation but is merely the result of widespread silicification of parts of the Smithton dolomite and also in places of the lower part of the overlying Dundas Group. Most of the cherts have the texture and characteristic jointing of the dolomite. Shallow solution depressions occur within areas mapped as Chert Sub-stage indicating the removal by solution of residual unsilicified dolomite (e.g. near where Fahey's Lane crosses the Smithton-Irishtown Railway). Complementarily, the previous authors write (p.28) concerning their "Dolomite Sub-stage" that in many cases the rock is partly or wholly silicified, the complete silicification producing a chert. At Nabageena irregular areas are replaced by chert while the dolomite also appears to be interbedded with cherts, which may also represent complete replacements of dolomite beds. The silicified oolite described above, which is part of the Chert Sub-stage was derived presumably from oolitic dolomite. If the Chert Sub-stage (excluding fringes regarded as belonging to the Dundas Group) and the Dolomite Sub-stage are combined as a single formation, the former being regarded as a silicified form of the latter, the combined outcrop makes a reasonable structural picture. (See Plate II.).

Revised Stratigraphic Sequence in the Smithton District.

The stratigraphic sequence as given by the previous authors is as follows :-

		Approx. thickness in feet.
(vi)	Upper Slate and Breccia Stage	
(v)	Dolomite Stage	5000-9000
(iv)	Slate, Breccia and Limestone Stage	4000
(iii)b	Chert Sub-stage	2000
(iii)a	Dolomite Sub-stage	1000
(ii)	Grey-Green Quartzite Stage	3000
(i)	White Quartzite Stage	1500

Of these formations we suggest that the White Quartzite Stage is a more silicified variant of the Grey-Green Quartzite Stage. As pointed out above we consider that the Chert Sub-stage (iii)b is a silicified variant of (iii)a, the Dol mite Sub-stage. We also consider that there is a large strike fault separating Stages (iv) and (v) causing a repetition of the sequence so that the Dolomite Stage (v) is a repetition of the Lower Dolomite (iii)a and (iii)b, and the Upper Slate and Breccia Stage (vi) is a repetition of the Lower Slate and Breccia Stage (iv).

The revised stratigraphic sequence of the Smithton district thus becomes :

			Stages of Nye, et al.	Approx. thickness
Cambrian	DUNDAS GROUP	Slates, breccias, basic lavas & tuffs.	(iv),(vi).	5000
Lower Cambrian or Late Pre-Cambrian	CARBINE GROUP	Smithton Dolomite	(iii)a, (iii)b,(v).	3000
		Bryant Mill Quartzite	(i), (ii).	3000

The previous authors have described two occurrences probably of the same bed of blue limestone which occurs within a few hundred feet of the highest exposures of the Dundas Group in the area. This limestone contains structures determined by Chapman as crinoid ossicles, and traces of other organic remains so far unidentifiable. The stratigraphic position of this limestone is uncertain. No limestones have been recorded from the Dundas Group in Tasmania although the correlates of the Dundas Group in South Australia do contain limestone. However, the facies of the Dundas Group in the Smithton district as elsewhere in Tasmania is typically eugeosynclinal whereas the facies of the correlates in South Australia are miogeosynclinal. On palaeogeographic grounds therefore, the limestone is somewhat alien in the Dundas Group. However, the overlying Junee Group in Western Tasmania normally contains limestone which often overlaps the basal conglomerates and rests on the Dundas Group. Perhaps the most likely interpretation therefore is that this crinoidal limestone should be correlated with the Junee Group of Ordovician Age. For the present however neither hypothesis can be substantiated or excluded.

Relation of Basic Volcanic Rocks and Tillite of Western Tasmania to Dundas Group.

In the Zeehan, Smithton and King Island areas we have an old series of basic amygdaloidal lavas which have many petrological features in common. The King Island occurrence is approximately 80 miles northwest of Smithton which in turn is 70 miles north of Zeehan. In between, petrologically similar rocks occur at Magnet. The King Island and Zeehan occurrences are underlain by tillites containing striated pebbles. At Smithton the lavas are underlain by a silicified breccia lithologically similar to phases of the King Island Tillite. At King Island the glacial beds and volcanic rocks are partly interbedded. At Zeehan the slates and tuffs immediately and conformably overlying the volcanic rocks contain Middle Cambrian trilobites identical with those occurring in the type area of the Dundas Group, eight miles to the east. In the type Dundas sequence there is a suite of lavas and tuffs petrologically similar to those at King Island and the other localities. These are interstratified with Middle Cambrian fossils. Also interstratified with fossiliferous Middle Cambrian beds in the type Dundas section are conglomerates and breccias which one of us (S.W.C.) and independently Elliston (who worked out the type section) consider to resemble tillites, but no unquestionable striated pebbles have yet been extracted from them. However, there are some striated pebbles preserved in the Museum of the Geology Department in the Adelaide University, which were collected by Waller from near Montezuma Falls, Dundas, and along the northeast Dundas tramline, and forwarded by Waller to Howchin for confirmation of their glacial origin. Although the recorded localities are not precise enough to pinpoint which of the conglomerates yielded the striated pebbles, Elliston's mapping has revealed that all the rocks outcropping in the area where these striated pebbles were collected belong to the Middle Cambrian Dundas Group.

This raises again questions about the age of the glaciation in the Adelaide Group of South Australia which has latterly been regarded as late Pre-Cambrian. It is of interest to note that near Broken Hill the

Torrowangie Group, which contains a basal tillite, has breccias and greywackes strikingly reminiscent of the Dundas Group; also that basic lavas petrologically similar to the Dundas lavas have recently been reported in the Torrowangie Group which recalls an earlier record of basic lavas by E.J. Kenny. A close search of this sequence for Cambrian dendroids and trilobites seems warrented.

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LOCALITY INDEX

	Latitude S.	Longitude.E.
Broken Hill	32°	141° 30'
Coward's Road	40° 51'	145° 8'
Deep Creek	40° 49'	145° 10'
Duck Bay	40° 50'	145° 4'
Dundas	41° 53'	145° 28'
Fahey's Lane	40° 54'	145° 11'
Groom's Road	40° 54'	145° 8'
King Island	39° 35'	143° 50'
Irishtown	40° 54'	145° 9'
Magnet	41° 28'	145° 26'
Montezeuma Falls	41° 50'	145° 27'
Nabageena	40° 59'	145° 8'
Park Point	40° 49'	145° 8'
Queenstown	42° 5'	145° 33'
Smithton	40° 52'	145° 7'
Tier Hill	40° 52'	145° 8'
Torrowangie	31° 28'	141° 29'
Trowutta	41°	145° 4'
Zeehan	41° 53'	145° 20'

EXPLANATION OF PLATES .

Plate I

Geological Map of the Smithton District of Tasmania.

Plate II

Figure 1 : Volcanic breccia, the lava fragments of which are depicted by the lighter colour and the chocolate shale by the darker colour.

Figure 2 : Volcanic bomb showing its shape and vesicular nature. Note its sharp boundary with the shale.

Figure 3 : Pillows of lava. See text figure for explanation.

Figure 4 : Silicified oolite showing the oval shaped oolites which vary in colour. The light coloured material between them is composed of very fine granular quartz.

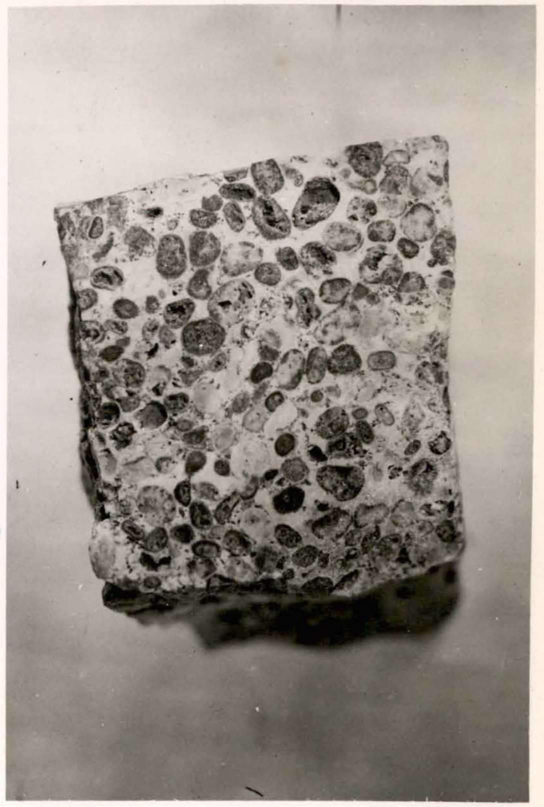
PLATE II

Figure 1 X·5

Figure 2 X·33

Figure 3

Figure 4 X 1·5



Copy of the manuscript of the paper

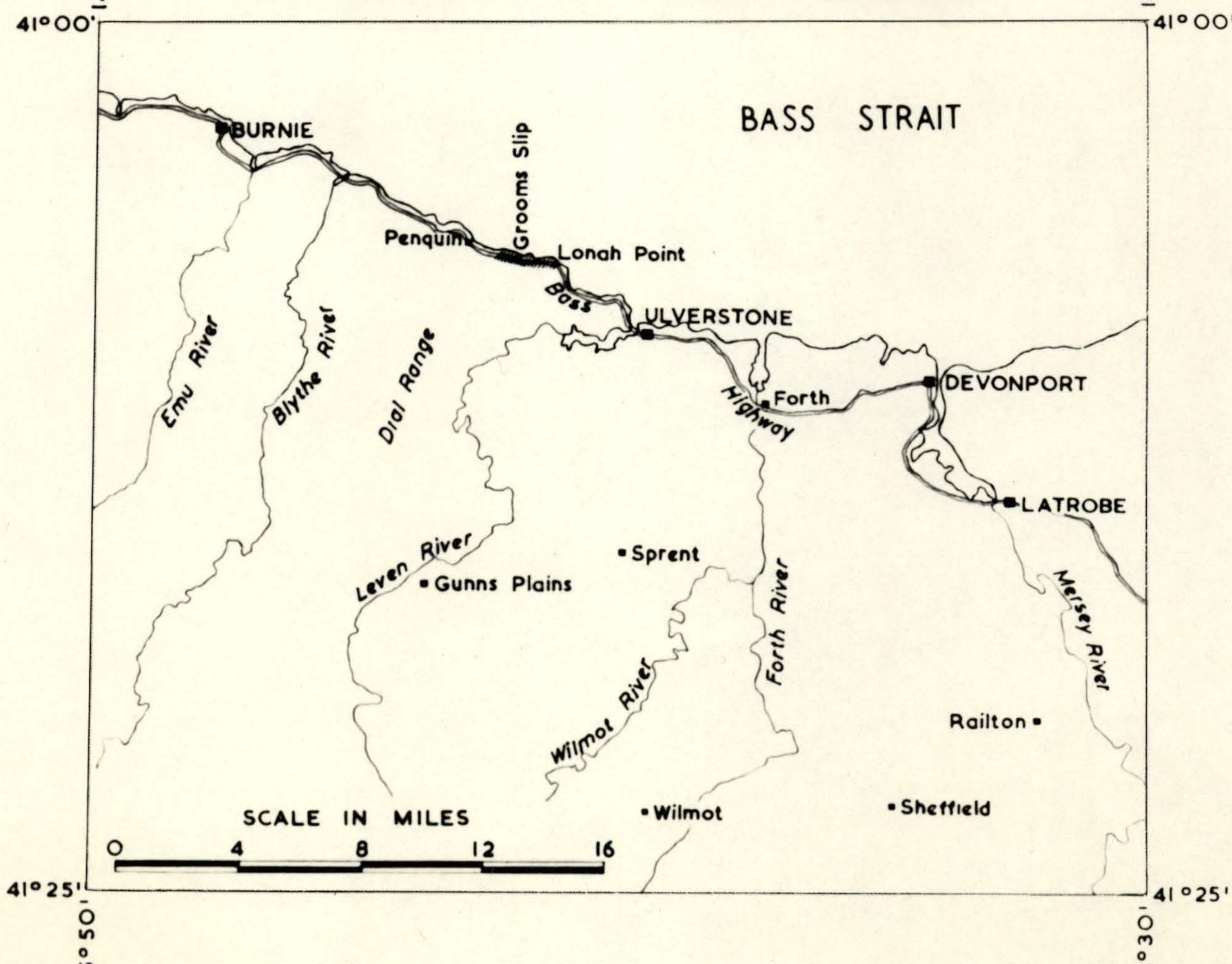
THE OCCURRENCE OF PILLOW LAVAS NEAR PENGUIN, TASMANIA.

By

BERYL SCOTT.

which will appear in the Papers and Proceedings of the Royal Society of Tasmania for 1952.

LOCALITY MAP OF N W COAST OF TASMANIA



THE OCCURRENCE OF PILLOW LAVAS NEAR PENGUIN, TASMANIA.

By: BERYL SCOTT.

Nye in 1931 reported the occurrence of dolerite of Lower Palaeozoic age at Groom's Slip, just east of Penguin along the north west coast of Tasmania. The reference to this report which appears in the Geological Index of Tasmania was brought to the notice of the author by Miss E.M. Smith, Geological Indexer for Tasmania, of the Bureau of Mineral Resources. It was decided to investigate the occurrence, especially as it appeared likely that it might be similar to the so-called dolerite of Smithton which has recently been re-interpreted by Carey and Scott (1952) as a suite of volcanic rocks similar to those outcropping along the south east coast of King Island and elsewhere on the west coast of Tasmania.

The dolerite at Groom's Slip has also proved to belong to a volcanic suite which, as elsewhere in Tasmania, is associated with tillite and laminated shales. The association of pillow lavas, tillite and laminated shales is so characteristic that taken with their structural and field relations the author has no hesitation in correlating them with the Dundas Group of Cambrian age.

Commencing a little east of Watcombe Beach, Penguin, the tillite and volcanic rocks outcrop as far east as Lonah Point, a distance of about two miles. The width of outcrop is no doubt due to a series of small anticlines and synclines and minor faulting but it also seems that the volcanic rocks are of a considerable thickness. The greatest development is at Groom's Slip.

Evidence that the rock is extrusive and not intrusive is revealed by the occurrence of well developed pillow structure. The pillows range in diameter from one to six feet and are stacked one on top of the other, the overlying pillows often being bulged over those underneath as illustrated by figure 1. Mostly they are ellipsoidal in shape but some have a tendency to an elongated twisted form as has been described by the author from King Island (Scott 1951). Some of the pillows bear the characteristic cavity in the centre. See figure 2.

Associated with the pillow lavas are normal massive lavas, which as at King Island and Smithton seem to overlie the shales and tillite but underlie the pillow lava, volcanic breccia and tuff. Vulcanicity must have begun before the deposition of the tillite and shales was complete because minor flows of lava are interbedded with the sediments.

In the hand specimen the pillow lava is the usual fine grained greyish green rock already described from the other areas. Microscopically, it consists of tiny laths of albite with intergranular augite and grains of ilmenite scattered throughout the rock. Occurring in the spaces between the plagioclase laths and augite granules are patches of pale green chlorite containing granules of secondary sphene. The albite has a composition Ab_{98} An_2 and in some parts of the rock is partly sericitized and chloritized. The augite is quite fresh and often has simple twinning.

Petrographically the rock is very similar to a basaltic type from King Island the analysis of which is similar to those of the pillow lavas from King Island and Smithton. These analyses have been listed for comparison with that of the Groom's Slip lava.

	I	II	III	IV	V
SiO_2	48.35	50.01	52.61	50.16	53.20
Al_2O_3	16.82	15.38	13.03	18.01	19.15
Fe_2O_3	2.85	4.86	3.90	13.98	7.72
FeO	10.21	9.21	8.48	4.15	3.87
MgO	4.46	5.85	5.10	1.84	2.89
CaO	9.55	6.35	7.26	1.40	1.24
Na_2O	3.78	4.77	5.60	4.43	5.17
K_2O	0.42	0.40	0.42	0.83	0.58
H_2O+	2.32	2.60	1.65)	)	
H_2O-	0.32	0.23	0.10)	2.10)	4.00
CO_2	n.dt.	0.13	0.05)	)	
TiO_2	0.78	0.73	0.72	2.00	1.74
MnO	0.10	0.21	0.19	Tr.	Tr.
P_2O_5	n.dt.	0.09	Tr.	0.25	0.30
S	-	-	0.08	Tr.	0.05
Total	99.96	100.82	99.19	99.15	99.91

I Spilite, Groom's Slip, Penguin, Tas. Anal. B. Scott.
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III Spilite (Pillow lava), King Island, Tas. Anal. B. Scott.
IV Mugearite (Pillow lava), Smithton, Tas. (Bulletin 41, p.69)
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(Note: The variation in the CaO, MgO, Fe_2O_3 content of the Smithton rocks is probably due to the replacement of the ferromagnesian mineral by iron ores, particularly haematite).

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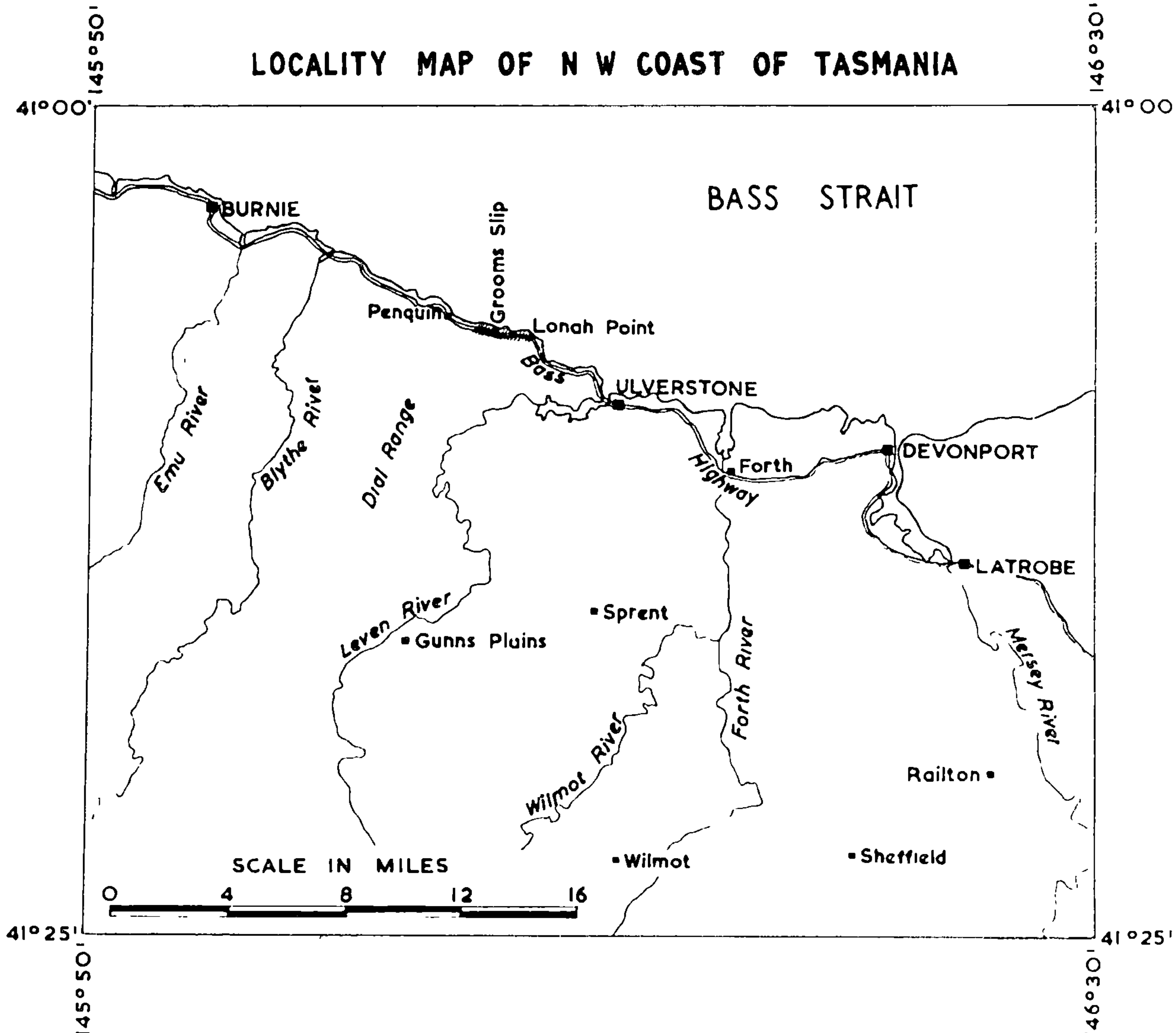

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DESCRIPTION OF PLATE

Figure 1: General view of pillows of lava illustrating the bulging effect of the pillows over each other.

Figure 2: Pillows of lava, one (near hammer) of which shows a central cavity.